CHAPTER 5 GREENHOUSE GAS EMISSIONS AND CLIMATE CHANGE

This section describes how the Proposed Action and alternatives potentially would affect the pace and extent of future changes in global climate. One of the key matters about which federal agencies must use their own judgment is determining how to describe the direct and indirect climate change-related impacts of a proposed action.[1] In this SEIS, the discussion compares projected decreases in greenhouse gas (GHG[TC "greenhouse gas (GHG" \f A \l "1"]) emissions from the Proposed Action and alternatives with GHG emissions from the No Action Alternative. The discussion of consequences of the Proposed Action and alternatives focuses on GHG emissions and their potential impacts on the climate system (atmospheric carbon dioxide [CO_2[TC "carbon dioxide (CO2" \f A \l "1"]] concentrations, temperature, sea level, precipitation, and ocean pH). For purposes of this analysis, the standards are assumed to remain in place for MYs after 2026 at the level of the MY 2026 standards set forth by the agency. This chapter presents results through 2100.

This chapter is organized as follows.

- Section 5.1, *Introduction,* introduces key topics on GHGs and climate change, including uncertainties in assessing climate change impacts.
- Section 5.2, *Affected Environment,* describes the affected environment in terms of current and anticipated trends in GHG emissions and climate.
- Section 5.3, *Analysis Methods*, outlines the methods NHTSA used to evaluate climate effects.
- Section 5.4, *Environmental Consequences*, describes the potential direct and indirect environmental impacts of the Proposed Action and alternatives. This description includes a projection of the direct and reasonably foreseeable indirect GHG emissions under each of the alternatives, as well as sector-wide and national GHG emissions estimates to provide context for understanding the relative magnitude of the Proposed Action and alternatives.

The cumulative impacts of the Proposed Action are discussed in Chapter 8, *Cumulative Impacts*. That chapter includes climate modeling that applies different assumptions about the effect of broader global GHG policies on emissions outside the U.S. passenger car and light truck fleets as well as qualitative discussions based on an appropriate literature review of the potential cumulative impacts of climate change on key natural and human resources.

5.1 Introduction

This SEIS draws primarily on panel-reviewed synthesis and assessment reports from the Intergovernmental Panel on Climate Change (IPCC)[TC "Intergovernmental Panel on Climate Change (IPCC)" \f A \l "1"] and the U.S. Global Change Research Program (GCRP)[TC "U.S. Global Change Research Program (GCRP)" \f A \l "1"], supplemented with past reports from the U.S. Climate Change

[1] Pursuant to Executive Order 13990, *Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis*, the Council on Environmental Quality (CEQ) rescinded its 2019 Draft National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emissions and is reviewing, for revision and update, the 2016 Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews. National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emissions; Notice of Rescission of Draft Guidance, 86 FR 10252 (Feb. 19, 2021).

Science Program (CCSP[TC "Climate Change Science Program (CCSP" \f A \l "1"]), the National Research Council, and the Arctic Council. It also cites EPA's *Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under the Clean Air Act* (EPA 2009), which relied heavily on past major international or national scientific assessment reports. NHTSA relies on assessment reports because these reports assess numerous individual studies to draw general conclusions about the state of climate science and potential impacts of climate change, as summarized or found in peer-reviewed reports. These reports are reviewed and formally accepted by, commissioned by, or in some cases authored by U.S. government agencies and individual government scientists; and in many cases reflect and convey the consensus conclusions of expert authors. These sources have been vetted by both the climate change research community and by the U.S. government. Even where assessment reports include consensus conclusions of expert authors, uncertainly still exists, as with all assessments of environmental impacts. See Section 5.1.1, *Uncertainty in the IPCC Framework*, on how uncertainty is communicated in the IPCC reports.

As with any analysis of complex, long-term changes to support decision-making, evaluating reasonably foreseeable impacts on the human environment involves many assumptions and uncertainties. For this reason, NHTSA relies on methods and data to analyze climate impacts that represent the best and most current information available on this topic and that have been subjected to extensive peer review and scrutiny. This SEIS draws on peer-reviewed literature that has been published since the release of the IPCC and the GCRP panel-reviewed reports. Because this recent literature has not been assessed or synthesized by an expert panel, these sources supplement, but do not supersede, the findings of the panel-reviewed reports.[2] In virtually every case, the recent literature corroborates the findings of the panel reports.

The level of detail regarding the science of climate change provided in this SEIS, as well as NHTSA's consideration of other studies that demonstrate the potential impacts of climate change on health, society, and the environment, is provided to help inform the public and decision-makers. This approach is consistent with federal regulations and with NHTSA's approach in its EISs for the MY 2011–2015 CAFE standards, MY 2012–2016 CAFE standards, Phase 1 HD standards, MY 2017–2025 CAFE standards, and the Phase 2 HD standards.

5.1.1 Uncertainty in the IPCC Framework

As with all environmental impacts, assessing climate change impacts of the Proposed Action and alternatives involves uncertainty. When agencies are evaluating reasonably foreseeable significant adverse environmental impacts and there is incomplete or unavailable information, the CEQ regulations require agencies to make clear that such information is lacking.[3] Assessing climate change impacts involves uncertainty, including with regard to discrete and localized impacts. Given the global nature of climate change and the need to communicate uncertainty to a variety of decision-makers, IPCC has focused considerable attention on developing a systematic approach to characterize and communicate this information. In this SEIS, NHTSA uses the system developed by IPCC to describe uncertainty

[2] The most recent comprehensive IPCC report is the Fifth Assessment Report (AR5). The IPCC's Sixth Assessment Report (AR6) is due to be released late summer 2021. Most of the references to IPCC in this report are to AR5. However, some preliminary results of AR6 have been published and are reflected where applicable within this report. Once released, NHTSA will incorporate AR6 findings into the Final SEIS to the maximum extent practicable.

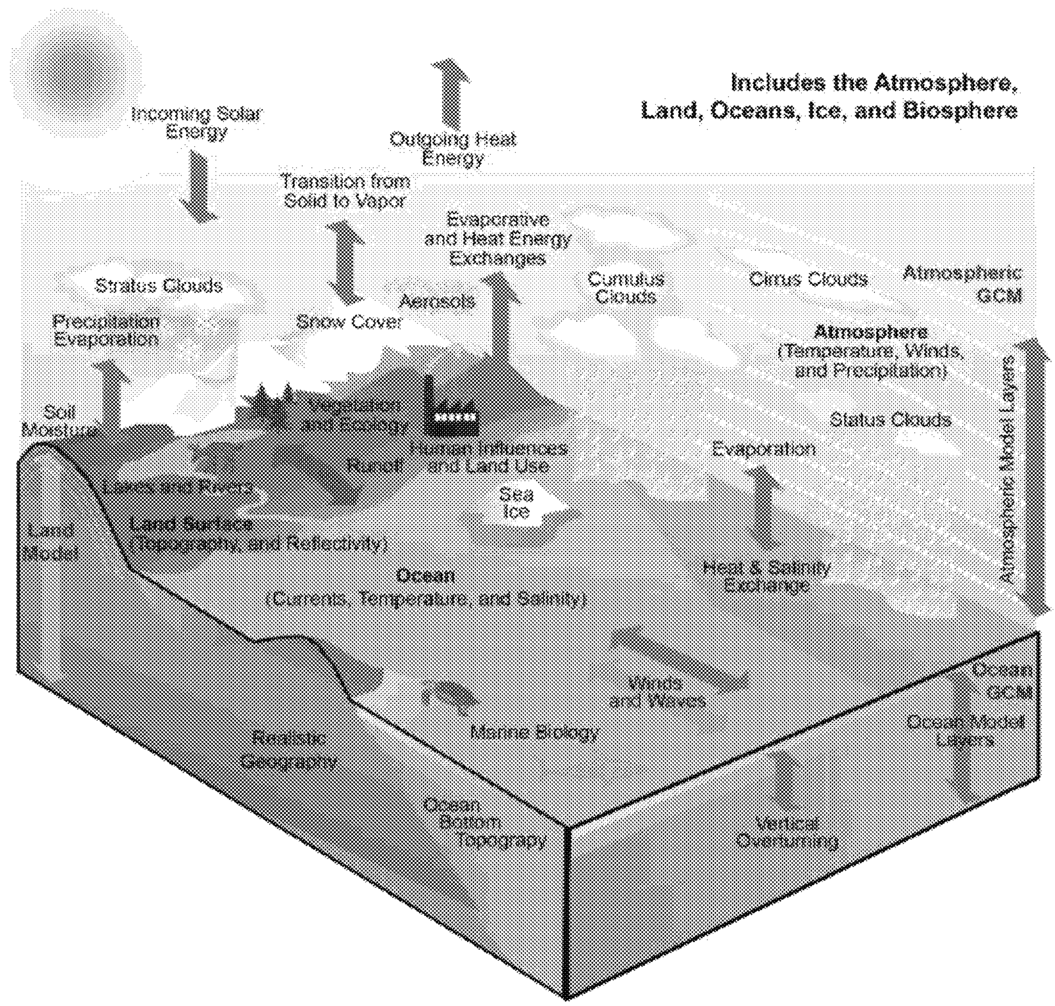
[3] 40 CFR § 1502.22 (2019).

associated with various climate change impacts. Consequently, the meanings of these IPCC terms are different from the language used to describe uncertainty elsewhere in the SEIS.

The IPCC reports communicate uncertainty and confidence bounds using commonly understood but carefully defined words in italics, such as *likely* and *very likely*, to represent likelihood of occurrence. The *IPCC Working Group I Fifth Assessment Report Summary for Policymakers* (IPCC WGI AR5*[TC "IPCC Working Group I Fifth Assessment Report Summary for Policymakers (IPCC WG1 AR5" \f A \l "1"]*) (IPCC 2013b) briefly explains this convention. The IPCC Guidance Notes for Lead Authors of the *IPCC AR5 on Addressing Uncertainties* (IPCC 2010) provides a more detailed discussion of the IPCC treatment of uncertainty. This SEIS uses the IPCC uncertainty language (noted in italics) when discussing qualitative environmental impacts on specific resources. The referenced IPCC documents provide a full understanding of the meaning of those uncertainty terms in the context of the IPCC findings. The IPCC WGI AR5 (IPCC 2013a) notes that the two primary uncertainties with climate modeling are model uncertainties and scenario uncertainties.

- **Model uncertainties.** These uncertainties occur when a climate model might not accurately represent complex phenomena in the climate system (see Figure 5.1.1-1 for a sample of processes generally represented in climate models). For some processes, the scientific understanding could be limited regarding how to use a climate model to "simulate" processes in the climate system. Model uncertainties can be differentiated into parametric and structural uncertainties.
- **Scenario uncertainties.** These uncertainties arise because of uncertainty in projecting future GHG emissions, concentrations, and forcings (e.g., from solar activity).

Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. Some Climate System Processes Included in Climate Models



Source: GCRP 2014
GCM = general circulation model[TC "GCM = general circulation model" \f A \l "1"]

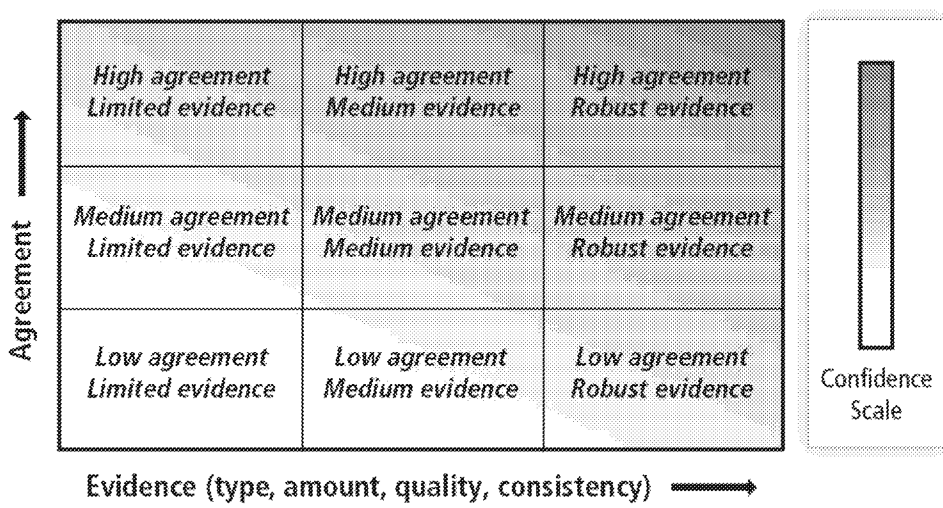
As stated in the IPCC WGI AR5, these types of uncertainties are described by using two metrics for communicating the degree of certainty: confidence in the validity of findings, expressed qualitatively, and quantified measures of uncertainties, expressed probabilistically. The confidence levels synthesize the judgments about the validity of the findings, determined through evaluation of the evidence and the degree of scientific agreement. The qualitative expression of confidence ranges from *very low* to *very high*, with higher confidence levels assigned to findings that are supported by high scientific agreement. The quantitative expression of confidence ranges from *exceptionally unlikely* to *virtually certain*, with higher confidence representing findings supported by robust evidence (Table 5.1.1-1). Figure 5.1.1-2 shows that the degree of confidence increases as evidence becomes more robust and agreement is greater.

Table [STYLEREF 3 \s]-[SEQ Table * ARABIC \s 3]. Standard Terms to Define the Likelihood of a Climate-Related Event

Likelihood Terminology	Likelihood of the Occurrence/Outcome
Virtually certain	99–100% probability
Very likely	90–100% probability
Likely	66–100% probability
About as likely as not	33–66% probability
Unlikely	0–33% probability
Very unlikely	0–10% probability
Exceptionally unlikely	0–1% probability

Notes:
Additional terms that were used in limited circumstances in the IPCC Fourth Assessment Report (AR4[TC "IPCC Fourth Assessment Report (AR4" \f A \l "1"]) (*extremely likely* = 95–100% probability, *more likely than not* ≥ 50–100% probability, and *extremely unlikely* = 0–5% probability) were also used in IPCC WGI AR5 when appropriate, and in the *Fourth National*

Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. Confidence Level as a Combination of Evidence and Agreement



Source: IPCC 2013a

5.1.2 Climate Change and Its Causes

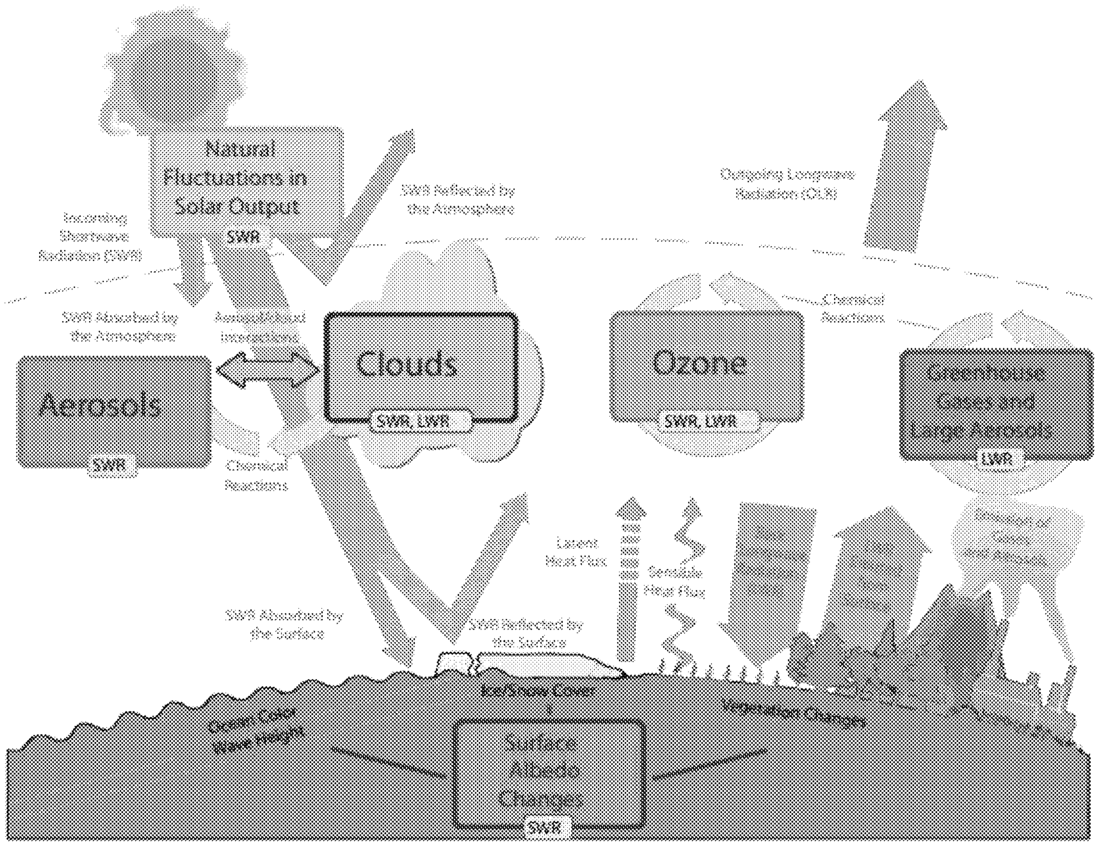
Global climate change refers to long-term (i.e., multi-decadal) trends in global average surface temperature, precipitation, ice cover, sea level, cloud cover, sea surface temperatures and currents, and other climate conditions. Earth absorbs energy from the sun and returns most of this energy to space as terrestrial infrared radiation. GHGs trap heat in the lower atmosphere (the atmosphere extending from Earth's surface to approximately 4 to 12 miles above the surface), absorb heat energy emitted by Earth's surface and lower atmosphere, and reradiate much of it back to Earth's surface, thereby causing warming. This process, known as the *greenhouse effect*, is responsible for maintaining surface temperatures that are warm enough to sustain life. Human activities, particularly fossil fuel combustion, lead to the presence of increased concentrations of GHGs in the atmosphere; this buildup of GHGs is changing the Earth's energy balance. IPCC states the warming experienced since the mid-20th century is due to the combination of natural climatic forcers (e.g., natural GHGs, solar activity) and human-made climate forcers (IPCC 2013a). IPCC concluded, "[h]uman influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea-level rise, and in changes in some climate extremes. … This evidence for human influence has grown since [the IPCC *Working Group 1 (WGI[TC "Working Group 1 (WG1" \f A \l "1"]) Fourth Assessment Report (AR4[TC "Fourth Assessment Report (AR4" \f A \l "1"])*]. IPCC reports that it is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century" (IPCC 2013a).

Although the climate system is complex, IPCC has identified the following drivers of climate change (Figure 5.1.2-1).

- **GHGs**. Primary GHGs in the atmosphere are water vapor, CO_2, nitrous oxide (N_2O)[TC "nitrous oxide (N2O)" \f A \l "1"], methane (CH_4)[TC "methane (CH4)" \f A \l "1"], and ozone (IPCC 2013a). Though most GHGs occur naturally, human activities—particularly fossil fuel burning—have significantly increased atmospheric concentrations of these gases (see IPCC 2013a for more information on human impacts on the climate and effects of different GHGs).
- **Aerosols.** Aerosols are natural (e.g., from volcanoes) and human-made particles in the atmosphere that scatter incoming sunlight back to space, causing cooling. Some aerosols are hygroscopic (i.e., attract water) and can affect the formation and lifetime of clouds. Large aerosols (more than 2.5 micrometers in size) modify the amount of outgoing long-wave radiation (IPCC 2013a). Other particles, such as black carbon, can absorb outgoing terrestrial radiation, causing warming. Natural aerosols have had a negligible cumulative impact on climate change since the start of the industrial era (IPCC 2013a).
- **Clouds**. Depending on cloud height, cloud interactions with terrestrial and solar radiation can vary. Small changes in the properties of clouds can have important implications for both the transfer of radiative energy and weather (IPCC 2013a).
- **Ozone.** Ozone is created through photochemical reactions from natural and human-made gases. In the troposphere, ozone absorbs and reemits long-wave radiation. In the stratosphere, the ozone layer absorbs incoming short-wave radiation (IPCC 2013a).
- **Solar radiation.** Solar radiation, the amount of solar energy that reaches the top of Earth's atmosphere, varies over time (IPCC 2013a). Solar radiation has had a negligible impact on climate change since the start of the industrial era compared to other main drivers (IPCC 2013a).
- **Surface changes**. Changes in vegetation or land surface properties, ice or snow cover, and ocean color can affect surface albedo.[4] The changes are driven by natural seasonal and diurnal changes (e.g., snow cover) as well as human influences (e.g., changes in vegetation type) (IPCC 2013a).

[4] Surfaces on Earth (including land, oceans, and clouds) reflect solar radiation back to space. This reflective characteristic, known as *albedo*, indicates the proportion of incoming solar radiation the surface reflects. High albedo has a cooling effect because the surface reflects rather than absorbs most solar radiation.

Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. Main Drivers of Climate Change



Source: IPCC 2013a
SWR = shortwave radiation; LWR = longwave radiation; OLR = outgoing longwave radiation[TC "°C = degrees Celsius" \f A \l "1"]

5.2 Affected Environment

This section describes the affected environment in terms of current and anticipated trends in GHG emissions and climate. Effects of emissions and the corresponding processes that affect climate are highly complex and variable, which complicates the measurement and detection of change. However, an increasing number of studies conclude that anthropogenic GHG emissions are affecting climate in detectable and quantifiable ways (IPCC 2013b; GCRP 2017).

This section discusses GHG emissions and climate change both globally and in the United States. NHTSA references IPCC and GCRP sources of historical and current data to report trends in GHG emissions and changes in climate change attributes and phenomena.

5.2.1 Greenhouse Gas Emissions and Aerosols—Historical and Current Trends

5.2.1.1 Global Greenhouse Gas Emissions

GHGs are gaseous constituents in the atmosphere, both natural and anthropogenic, that absorb and reemit terrestrial infrared radiation. Primary GHGs in the atmosphere are water vapor, CO_2, N_2O[TC "nitrous oxide (N2O)" \f A \l "1"], CH_4[TC "methane (CH4)" \f A \l "1"], and ozone. These GHGs occur naturally and because of human activity.[5] Other GHGs, such as the fluorinated gases,[6] are almost entirely anthropogenic in origin and are used in commercial applications such as refrigeration and air conditioning and industrial processes such as aluminum production.

By far the GHG with the largest contribution to warming is CO_2. Global atmospheric CO_2 concentrations have increased 48.4 percent, from approximately 278 parts per million (ppm)[TC "parts per million (ppm)" \f A \l "1"] in 1750 (IPCC 2013a) to approximately 412 ppm in 2020 (NOAA 2021). Isotopic- and inventory-based studies make clear that this rise in the CO_2 concentration is largely a result of the release of carbon that had been stored underground and then used to combust fossil fuels[XE "fossil fuels"] (coal, petroleum, and natural gas) to produce electricity, heat buildings, and power motor vehicles and airplanes, among other uses (IPPC 2013a). In 2018, CO_2 emissions accounted for 73 percent of global GHG emissions on a global warming potential (GWP[TC "global warming potential (GWP" \f A \l "1"])-weighted basis,[7] followed by CH_4 (18 percent), N_2O (7 percent), and fluorinated gases (2 percent) (WRI 2021).[8] Atmospheric concentrations of N_2O and CH_4 increased approximately 20 and 150 percent, respectively, over roughly the same period (IPCC 2013a).

GHGs are emitted from a wide variety of sectors, including energy, industrial processes, waste, agriculture, and forestry. The energy sector is the largest contributor of global GHG emissions, accounting for 78 percent of global emissions in 2018; other major contributors of GHG emissions are agriculture (13 percent) and industrial processes (6 percent) (WRI 2021). Transportation CO_2 emissions—from the combustion of petroleum-based fuels—have increased by 75 percent from 1990 to 2018 and account for roughly 15 percent of total global GHG emissions (WRI 2021).[9]

In general, global GHG emissions continue to increase, although annual increases vary according to factors such as weather, energy prices, and economics. Recent trends in observed carbon emissions are comparable to projected emissions from the most fossil fuel-intensive emissions scenario (A1Fi) in the *IPCC Special Report on Emissions Scenarios* (IPCC 2000) and the highest emissions scenario representing unmitigated GHG concentration increases through the century (RCP8.5) as established by the more recent Representative Concentration Pathways (RCP[TC "Representative Concentration Pathways (RCP" \f A \l "1"])[10] (IPCC 2013a).

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[5] Although humans have always contributed some level of GHG emissions to the atmosphere through activities like farming and land clearing, substantial anthropogenic contributions did not begin until the mid-1700s with the onset of the Industrial Revolution. People began burning coal, oil, and natural gas to light their homes, to power trains and cars, and to run factories and industrial operations.

[6] Fluorinated GHGs or gases include perfluorocarbons, hydrofluorocarbons (HFCs), sulfur hexafluoride, and nitrogen trifluoride.

[7] Each GHG has a different radiative efficiency (i.e., the ability to absorb infrared radiation) and atmospheric lifetime. To compare their relative contributions, GHG emission quantities are converted to carbon dioxide equivalent (CO_2e) using the 100-year time horizon GWP as reported in IPCC's *Fourth Assessment Report (AR4): The Physical Science Basis* (IPCC 2007).

[8] These global GHG estimates *do not* include contributions from land-use change and forestry or international bunker fuels.

[9] The energy sector is largely composed of emissions from fuels consumed in the electric power, transportation, industrial, commercial, and residential sectors. The 15 percent value for transportation is therefore included in the 78 percent value for energy.

[10] The Representative Concentration Pathways (RCPs) were developed for the IPCC AR5 report. They define specific pathways to emission concentrations and radiative forcing in 2100. The RCPs established four potential emission concentration futures, a business-as-usual pathway representing continued GHG concentration increases (RCP8.5), two stabilization pathways (RCP6.0, 4.5), and an aggressive reduction pathway (RCP2.6).

5.2.1.2 U.S. Greenhouse Gas Emissions

Most GHG emissions in the United States are from the energy sector, with the majority of those emissions being CO_2 emissions coming from the combustion of fossil fuels. CO_2 emissions from fossil fuel combustion alone account for 74 percent of total U.S. GWP-weighted emissions (EPA 2021a), with the remaining 26 percent contributed by other energy-related activities (e.g., fugitive emissions from natural gas systems), industrial processes and product use, agriculture and forestry, and waste. CO_2 emissions due to combustion of fossil fuels are from fuels consumed in the transportation (37 percent of fossil fuel combustion CO_2 emissions), electric power (33 percent), industrial (17 percent), residential (7 percent), and commercial (5 percent) sectors (EPA 2021a). In 2019, U.S. GHG emissions were estimated to be 6,558.3 million metric tons carbon dioxide equivalent ($MMTCO_2e$) (EPA 2021a),[11] or approximately 14 percent of global GHG emissions (WRI 2021).[12]

Similar to the global trend, CO_2 is by far the primary GHG emitted in the United States, representing 80 percent of U.S. GHG emissions in 2019 (EPA 2021a) (on a GWP-weighted basis) and accounting for 16 percent of total global CO_2 emissions (WRI 2021).[13] When U.S. CO_2 emissions are apportioned by end use, transportation is the single leading source of U.S. emissions from fossil fuels, causing over one-third of total CO_2 emissions from fossil fuels (EPA 2021a).[14] CO_2 emissions from passenger cars and light trucks have increased 14 percent since 1990 (EPA 2021a) and account for 58 percent of total U.S. CO_2 emissions from transportation (EPA 2021a). This increase in emissions is attributed to a 47 percent increase in vehicle miles traveled (VMT[TC "vehicle miles traveled (VMT" \f A \l "1"]) because of population growth and expansion, economic growth, and low fuel prices. Additionally, the rising popularity of sport utility vehicles and other light trucks with lower fuel economy than passenger cars has contributed to higher emissions (EPA 2021a; DOT 2017). Although emissions typically increased over this period, emissions declined from 2008 to 2009 because of decreased economic activity associated with the recession at the time (EPA 2019a). The coronavirus disease 2019 (COVID-19) pandemic resulted in another decrease in emissions in 2020. Emissions in the first half of 2020 were 8.8 percent lower than the same period in 2019. The decline in emissions leveled off in the second half of the year as restrictions began to relax and economic activity increased (Liu et al. 2020). Figure 5.2.1-1 shows the proportion of U.S. CO_2 emissions attributable to the transportation sector and the contribution of each mode of transportation to those emissions.

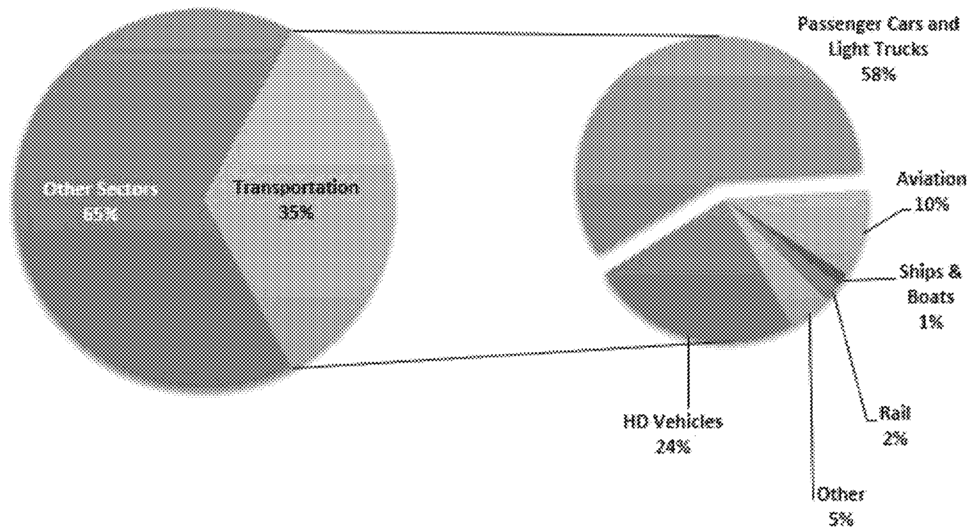
[11] Most recent year for which an official EPA estimate is available, excluding emissions and sinks from land-use change and forestry (EPA 2019a).

[12] Based on global and U.S. estimates for 2018, the most recent year for which a global estimate is available. Excluding emissions and sinks from land-use change and forestry.

[13] The estimate for global emissions from the World Resources Institute is for 2018, the most recent year with available data for all GHGs. It excludes emissions and sinks from land use change and forestry.

[14] Apportioning by end use allocates emissions associated with electricity generation to the sectors (residential, commercial, industrial, and transportation) where it is used.

Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. Contribution of Transportation to U.S. Carbon Dioxide Emissions by Mode (2019)



Source: EPA 2021a
HD = heavy-duty

Although CO_2 emissions represent the vast majority of the U.S. contribution to warming (80.1 percent), CH_4 accounts for 10.1 percent of U.S. GHGs on a GWP-weighted basis, followed by N_2O (7.0 percent) and the fluorinated gases (2.8 percent) (EPA 2021a).

5.2.1.3 Black Carbon and Other Aerosols

Aerosols are solid or liquid particles suspended in the Earth's atmosphere. The chemical composition of aerosols varies enormously and can include sulfates, nitrates, dust, black carbon, and other chemical species (IPCC 2013a; CCSP 2009). Aerosols are either emitted directly from a source (e.g., power plants, forest fires, and volcanoes) into Earth's atmosphere or chemically created in the atmosphere from gases (IPCC 2013a; CCSP 2009). Depending on meteorological conditions and other factors, aerosols typically remain in Earth's atmosphere from days to weeks (IPCC 2013a). Their relatively short lifetimes can create regional areas of high aerosol concentrations nearby as well as some distance downwind from emissions source(s) (IPCC 2013a).

An aerosol's impact on climate depends on its composition. Some aerosols, such as sulfates, reflect incoming sunlight back to space, causing a cooling effect; other aerosols, such as black carbon, absorb incoming sunlight, causing a warming effect (CCSP 2009; IPCC 2013a). In addition, some aerosols attract moisture or water vapor and can affect the lifetime and reflectivity of clouds. Overall, IPCC (2013a) states that there is *high confidence* that aerosols have offset a substantial portion of global mean forcing by cooling Earth's atmosphere from the reflection of incoming sunlight and their interaction with clouds, though large uncertainties exist. The overall effect of aerosols on precipitation is not known at the global scale, and this topic continues to be an active area of research (IPCC 2013a).

Among the aerosols, black carbon has attracted much attention because of its strong impact on Earth's energy balance. Black carbon is an aerosol that forms during incomplete combustion of certain fossil fuels (primarily coal and diesel) and biomass (primarily fuel wood and crop waste). There is no single accepted method for summarizing the range of effects of black carbon emissions on the climate or representing these effects and impacts in terms of carbon dioxide equivalent (CO_2e[TC "carbon dioxide equivalent (CO2e" \f A \l "1"]); significant scientific uncertainties remain regarding black carbon's total climate effect. The interaction of black carbon (and other co-emitted aerosols) with clouds is especially poorly quantified (IPCC 2013a), and this factor is key to any attempt to estimate the net climate impacts of black carbon. Although black carbon is likely to be a contributor to climate change, it is not feasible to quantify black carbon climate impacts in an analysis of the Proposed Action and alternatives.

Passenger cars and light trucks (especially those that are diesel-powered passenger cars and diesel-powered light trucks) contribute to U.S. emissions of black carbon, but there is no evidence to suggest that the alternatives would differ substantially in terms of their impact on black carbon and aerosol emissions. For further information on black carbon and aerosol emissions, climatic interactions, and net radiative effect, see Section 5.1.6 of the *Phase 2 Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles Final EIS* (NHTSA 2016a).

5.2.2 Climate Change Trends

In its most recent assessment of climate change (IPCC WGI AR5), IPCC states that, "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased" (IPCC 2013a). Numerous long-term changes in climate have been observed at continental and global scales (IPCC 2013a), and evidence indicates unambiguously that Earth's warming "over the last half century … has been driven primarily by human activity." IPCC concludes that, at continental and global scales, numerous long-term changes in climate have been observed. Additionally, IPCC and the GCRP include the following trends observed over the 20th century as further supporting the evidence of climate-induced changes:

- Most land areas have *very likely* experienced warmer and/or fewer cold days and nights along with warmer and/or more frequent hot days and nights (IPCC 2014a; GCRP 2017).
- Cold-dependent habitats are shifting to higher altitudes and latitudes, and growing seasons are becoming longer (IPCC 2014a; GCRP 2017).
- Sea level is rising, caused by thermal expansion of the ocean and melting of snowcaps and ice sheets (IPCC 2013a; GCRP 2017).
- More frequent weather extremes such as droughts, floods, severe storms, and heat waves have been observed (IPCC 2013a; GCRP 2017).
- There is *high confidence* that oceans are becoming more acidic because of increasing absorption of CO_2 by seawater, which is driven by a higher atmospheric concentration of CO_2 (IPCC 2013a; UN 2016; GCRP 2017). Recent assessment found that the oceans have become about 30 percent more acidic over the last 150 years since the Industrial Revolution (GCRP 2017).

Developed countries, including the United States, have been responsible for the majority of GHG emissions since the mid-1800s and still have some of the highest GHG emissions per capita (WRI 2021). While annual emissions from developed countries have been relatively flat over the last few decades, world population growth, industrialization, and increases in living standards in developing countries are expected to cause global fossil-fuel use and resulting GHG emissions to grow substantially. Global GHG emissions since 2000 have been increasing nearly three times faster than in the 1990s (IPCC 2013a).

Based on the current trajectory, IPCC projects that atmospheric CO_2 concentration could rise to more than three times preindustrial levels by 2100 (IPCC 2013a). The effects of the CO_2 emissions that have accumulated in the atmosphere prior to 2100 will persist well beyond 2100. If emissions from both developed and developing countries are not reduced dramatically in the coming decades, this elevation in atmospheric CO_2 concentrations is likely to persist for many centuries, with the potential for temperature anomalies continuing much longer (IPCC 2013a).

5.2.2.1 Climate Change Attributes

The climate change attributes of temperature, sea-level rise, precipitation, and ocean pH provide evidence of rapid climate change.

Temperature

Climate change is evidenced, in part, by increases in surface temperatures over time. The sections that follow discuss radiative forcing, average temperatures, and extreme temperatures as they relate to climate change.

Radiative Forcing

Radiative forcing (RF[TC "radiative forcing (RF" \f A \l "1"]) describes the magnitude of change in energy fluxes caused by a specific driver—in this case, anthropogenic GHGs—that can alter the Earth's energy budget. Positive RF leads to warming while negative RF leads to cooling (IPCC 2013a). GHGs have a positive RF. Total anthropogenic RF has increased by 2.29 watts per square meter (W/m^2) (plus 1.04 or minus 1.16 W/m^2) and is responsible for the observed warming (IPCC 2013a). The RF from increased atmospheric CO_2 concentration alone is estimated to be 1.68 W/m^2 (plus or minus 0.35 W/m^2) (IPCC 2013a). Previous estimates of total anthropogenic RF had, in fact, underestimated recent changes in RF: "The total anthropogenic RF best estimate for 2011 is 43 percent higher than that reported in AR4 for the year 2005" (IPCC 2013a). Most recently, the net heat uptake rate has been shown to be increasing. From mid-2005 to mid-2019, RF estimates from both in situ and satellite observations were shown to be 0.77 W/m^2 (plus or minus 0.06 W/m^2) due to an increase in absorbed solar radiation associated with decreased reflection by clouds and sea ice and a decrease in outgoing longwave radiation due to increases in trace gases and water vapor (Loeb et al. 2021). Future projections of RF are captured in the RCPs used to model future climate conditions. These RCPs are named according to the amount of change in RF in 2100 relative to preindustrial conditions (prior to 1750): +2.6, +4.5, +6.0, and +8.5 W/m^2 (GCRP 2017).

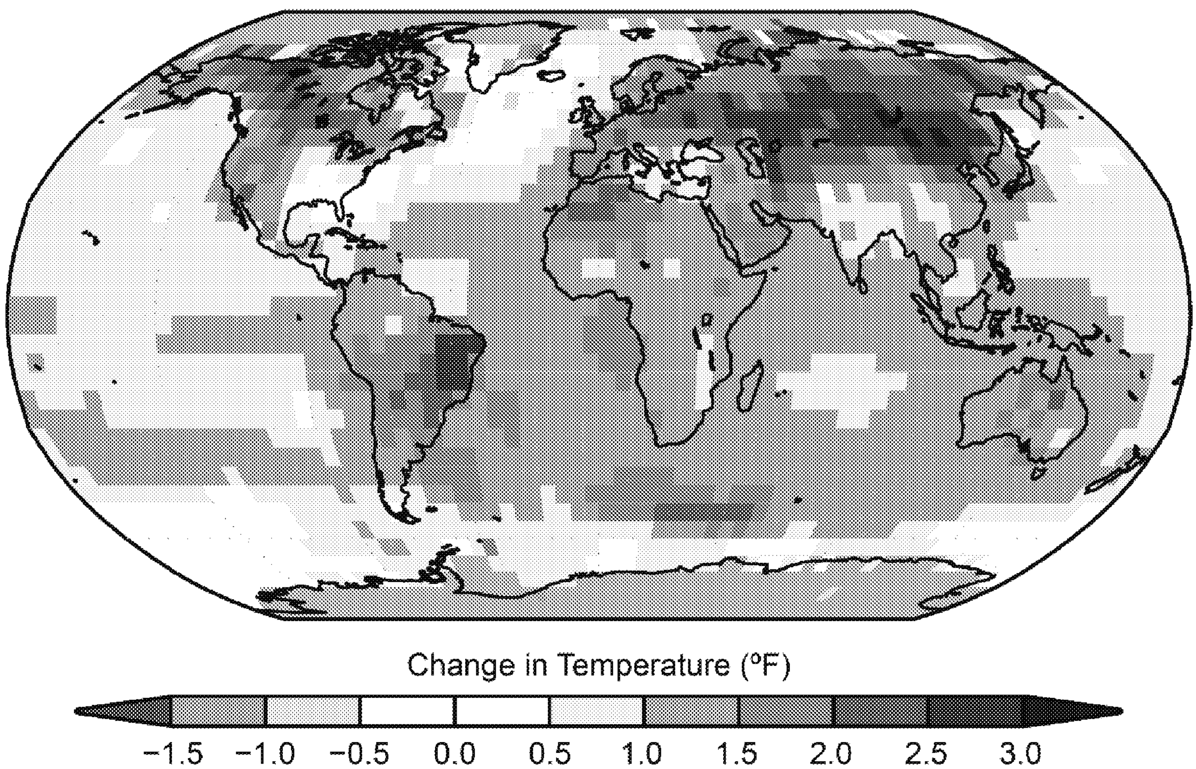
Average Temperatures

Annual average surface temperatures have increased across much of the globe in recent decades with "sixteen of the last 17 years" being "the warmest ever recorded by human observations" (GCRP 2017) (Figure 5.2.2-1). Annual average global temperature has increased by 1.0°C (1.8°F) from 1901 to 2016, and global temperatures are rising at an increasing rate. The years 2016 and 2020 were the hottest years on record globally, at about 0.94°C (1.69°F) above the 20th century average of 13.9°C (57.0°F) (Voosen 2021).[15]

[15] The global temperatures in 2016 were influenced by strong El Niño conditions that prevailed at the beginning of the year.

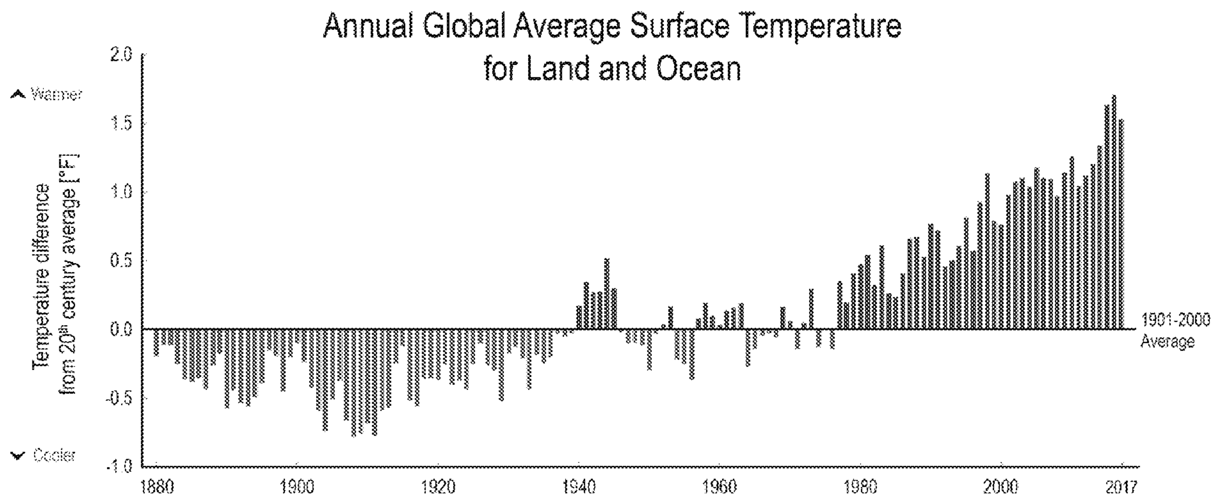
IPCC projects a continuing increase in global mean surface temperature over the course of this century, with a *likely* range of increase between 0.3°C (0.5°F) and 4.8°C (8.6°F) for the period of 2081 to 2100 compared with the baseline period of 1986 to 2005. The lower value corresponds to substantial future mitigation of carbon emissions (RCP2.6), with considerable short-term mitigation efforts, including an overall decrease in global CO_2 emissions starting in 2020 and declining to zero in 2100 (IPCC 2013a). The next most stringent scenario (RCP4.5) also has considerable short-term mitigation efforts with global CO_2 emissions peaking around 2040 (IPCC 2013a). For further information on observed and projected global climate change trends, see IPCC 2013a and GCRP 2018a.

Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. Global Surface Temperature Anomalies in Degrees Fahrenheit from 1986 to 2015 Relative to 1901 to 1960



Source: GCRP 2017
°F = degrees Fahrenheit

Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. Annual Global Average Surface Temperature Increases of About 0.9°C (1.6°F) from 1880 to 2016



Source: GCRP 2018b
°F = degrees Fahrenheit

Surface temperatures are not rising uniformly around the globe. Warming has been particularly pronounced in the Arctic (GCRP 2017). The average Arctic temperature has increased at almost twice the global average rate over at least the past several decades (GCRP 2017). Similar to the global trend, the U.S. average temperature has increased about 1.0°C (1.8°F) warmer than it was in 1895, and this rate of warming is increasing—most of the warming has occurred since 1970 (GCRP 2017). Some areas of the southeast region of the United States have experienced "warming holes," as indicated by 20th century temperature observations, suggesting minor to no warming trends since 1901 (GCRP 2017).

The oceans have a large heat capacity and have been absorbing more than 90 percent of warming caused by anthropogenic GHG emissions (GCRP 2017). Due to Earth's thermal inertia—whereby oceans absorb and dissipate heat to the atmosphere over a long period of time—warming could continue for centuries, even after atmospheric CO_2 is stabilized or reduced.

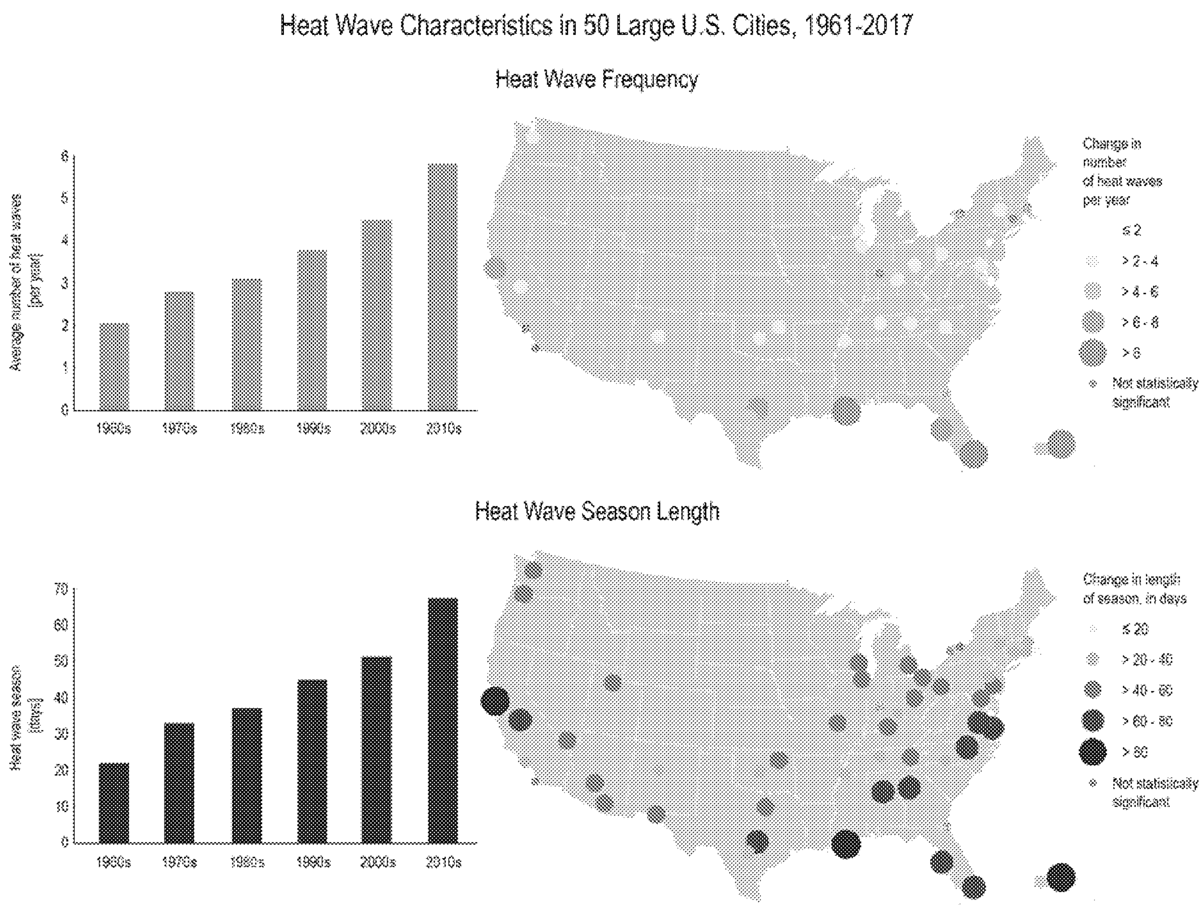
Multiple lines of evidence have recorded increasing average temperatures, including measurements from weather balloons and more recently satellites (GCRP 2017). In addition, higher temperatures have also been independently confirmed by other global observations. For example, scientists have documented shifts to higher latitudes and elevations of certain flora and fauna habitat (GCRP 2017). In high and mid-northern latitudes, the growing season increased an average of approximately 2 weeks during the second half of the 20th century (IPCC 2014b; GCRP 2014), and plant flowering and animal spring migrations are occurring earlier (EPA 2009; IPCC 2014b; GCRP 2014).

Extreme Temperatures

In many regions, extreme temperatures have changed substantially since about 1950. Extreme temperatures have changed both in frequency and intensity. As mean temperatures increase, the IPCC indicates it is *virtually certain* that there will be more hot and fewer cold temperature extremes; increases in the frequency, duration, and magnitude of hot extremes along with heat stress are expected; however, occasional cold winter extremes will continue to occur (IPCC 2013a). Hot days, hot nights, and heat waves have become more frequent; cold days, cold nights, and frost have become less frequent ([REF _Ref532830016 \h * MERGEFORMAT]) (EPA 2009; IPCC 2013a; GCRP 2017). Since 1950, the frequency of heat waves in the United States has increased, although in many regions the heat waves recorded in the 1930s remain the most severe on record (GCRP 2017). Recent heat waves in the United States have been significant, and recent modeling shows that anthropogenic climate change is projected to dominate heat wave occurrence in the western United States and Great Lakes region as early as this decade (Lopez et al. 2018).

Additionally, fewer unusually cold days occurred in the past few decades. The number of extreme cold waves peaked in the 1980s and reached a record low in the 2000s, with records dating back to at least 1895 (coincident with the expansion of the instrumental record) (GCRP 2017). Long-term warming driven by anthropogenic GHG emissions increases the likelihood of extreme temperatures and record warmth (Knutson et al. 2018; Meehl et al. 2016; Vogel et al. 2019a). According to IPCC, it is now considered *very likely* that humans have contributed to extreme heat events since the middle of the 20th century and it is *likely* that human activities have doubled the probability of extreme heat events in some regions (IPCC 2013a). For example, the likelihood of consecutive years with record-breaking annual average temperatures from 2014 to 2016 was negligible (less than 0.03 percent) in the absence of human influence (Mann et al. 2017). Additionally, the 2017 heat wave in southern Europe was found to be at least three times more likely today than it was in 1950 due to anthropogenic climate change (Kew et al. 2018). Recent literature continues to support and strengthen such findings, projecting both geographic and temporal increases in extreme heat by the late century (Dahl et al. 2019). These projections result from the general warming trend, rather than a specific RCP scenario or timeframe.

Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. Heat Waves Increasing in Frequency and Duration from 1961 to 2017



Source: GCRP 2018c

Sea-Level Rise

Global temperature increases contribute to sea-level rise. The sections that follow discuss contributions to sea-level rise, observed global sea-level rise, and observed regional sea-level rise, respectively.

Contributions to Sea-Level Rise

Higher temperatures cause global sea level to rise due to both thermal expansion of ocean water and an increased transfer of water from glaciers and ice sheets to the ocean. Since the early 1970s, the majority of observed sea-level rise has come from these sources. Other factors, such as changing ocean currents and vertical land adjustments, also affect local sea-level rise. IPCC concludes that it is *very likely* that human contributions to sea-level rise are substantial (IPCC 2013a).

Between 1971 and 2010, global ocean temperature warmed by approximately 0.25°C (0.45°F) in the top 200 meters (approximately 660 feet) (IPCC 2013a). In the top 700 meters (approximately 2,300 feet) of the ocean column, warming contributed an average of 0.6 millimeter (plus or minus 0.2 millimeter) (0.024 inch plus or minus 0.008 inch) per year to sea-level rise (IPCC 2013a). IPCC concludes that mountain glaciers, ice caps, and snow cover have declined on average, further contributing to sea-level rise. Losses from the Greenland and Antarctic ice sheets *very likely* contributed to sea-level rise from 1993 to 2010, and satellite observations confirm that they have contributed to sea-level rise in subsequent years (IPCC 2013a). Dynamic ice loss (i.e., the transfer of ice from land-based ice sheets to the ocean, which can accelerate following the collapse of supporting ice shelves) explains most (up to 74 percent) of the Antarctic net mass loss and about half of the Greenland net mass loss (IPCC 2013a).

These contributions to sea-level rise are expected to continue throughout this century. According to the IPCC, ocean warming is projected to continue throughout the 21st century, and all RCP scenarios project year-round reductions in Arctic sea ice (IPCC 2014b). Global glacier volume (excluding the Greenland and Antarctic ice sheets and glaciers on the periphery of Antarctica) is projected to decrease from 15 to 85 percent by the end of the 21st century relative to the baseline period from 1986 to 2005 (between the low estimate for RCP2.6 and the high estimate for RCP8.5) (IPCC 2013a, 2014a). While the Greenland ice sheet is currently contributing more to global sea-level rise, Antarctica could become the larger contributor by end-of-century due to rapid retreat of ice stream and glaciers draining the ice sheet (IPCC 2019a). Recent modeling indicates that the Antarctic ice sheet contribution to sea-level rise is projected to continue at about the current rate if Paris Agreement targets are reached (i.e., limiting warming to 2°C [3.6°F] or less). However, warming of 3°C [5.4°F] consistent with current policies has the potential to increase the contribution of Antarctic ice loss to sea-level rise to about 0.5 centimeter (0.2 inch) per year from 2060 to 2100, roughly 10 times faster than current rates (DeConto et al. 2021). New projections also show that limiting global warming to 1.5°C (2.7°F) above pre-industrial levels could halve land ice contribution to sea-level rise during the 21st century, resulting in median land ice contributions to sea-level rise ranging from 13 to 42 centimeters (5.1 to 16.5 inches) by 2100, with the higher projection due to rapid mass loss from the Antarctic ice sheet (Edwards et al. 2021).

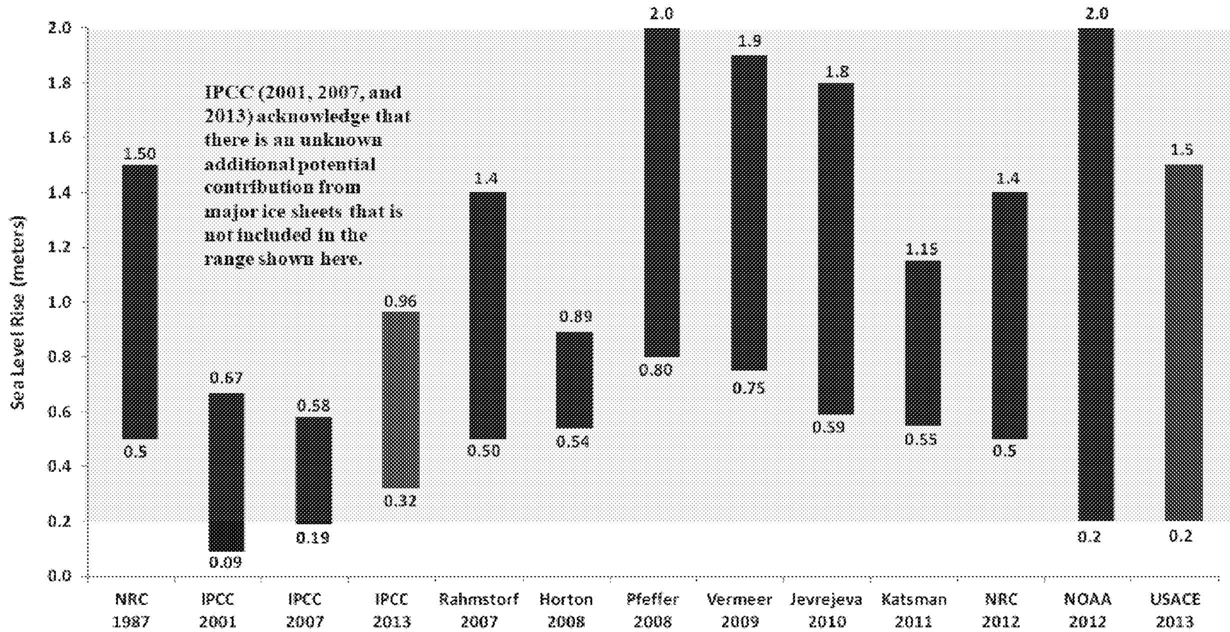
Warming ocean temperatures affect ice sheet stability through submarine melting and altering the dynamics of ice shelves, ice streams, and glaciers. The interconnectedness of the ocean and cryosphere (e.g., glaciers and ice streams that drain the Greenland and Antarctic ice sheets into the ocean) can lead to compounding impacts, whereby ocean warming triggers dramatic ice sheet instability through enhanced melting and calving at glacier and ice stream fronts. In turn, the nonlinear relationship between ocean warming and ice mass loss could be a large driver of future global sea-level rise (IPCC 2019a).

Global Sea-Level Rise

Global mean sea level rose by about 1.0 to 1.7 millimeters (0.04 to 0.07 inch) per year from 1901 to 1990, a total of 11 to 14 centimeters (4 to 5 inches) (GCRP 2017). After 1993, global mean sea level rose at a faster rate of about 3 millimeters (0.12 inch) per year (GCRP 2017). Consequently, global mean sea level has risen by about 7 centimeters (3 inches) since 1990, and by 16 to 21 centimeters (7 to 8 inches) since 1900 (GCRP 2017). Looking forward, IPCC projects that global sea level is likely to rise 29 to 59 centimeters (11.4 to 23.2 inches) for RCP2.6 and 61 to 110 centimeters (24.0 to 43.3 inches) for RCP8.5 compared to 1986 to 2005 (Oppenheimer et al. 2019).

In addition, other studies that consider dynamic mass loss from major ice sheets indicate that sea-level rise could be even greater (Figure 5.2.2-4) (Robel et al. 2019; Bamber et al. 2019). Most of these studies project a higher sea-level rise than the IPCC studies. In 2017, NOAA found that there is *very high confidence* (more than a 9 in 10 chance) that global mean sea level will rise 0.2 to 2.7 meters (7.9 inches to 8.9 feet) by 2100 (Sweet et al. 2017a). Increasing anthropogenic GHG emissions would increase the risks posed by greater warming and sea-level rise (IPCC 2014a). Records of paleo sea level indicate that, when global mean temperatures increased to 2°C [3.6°F] above preindustrial levels, global mean sea level was 5 meters (16.4 feet) higher than current levels (IPCC 2013a).

Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. End-of-Century Estimates of Maximum and Minimum Global Mean Sea-Level Rise (2090–2100)



Source: USACE 2014
NRC = National Research Council; IPCC = Intergovernmental Panel on Climate Change; NOAA = National Oceanic and Atmospheric Administration; USACE = U.S. Army Corps of Engineers

Regional Sea-Level Rise

Sea-level rise is not uniform across the globe, primarily because dynamic ocean heights are adjusted by ocean currents and because coastline elevations change through time as a result of regional tectonics, subsidence, and isostatic rebound. The largest increases in sea level since 1992 have occurred in the western Pacific and eastern Indian Oceans; meanwhile, sea level in the eastern Pacific and western Indian Oceans has actually been falling (IPCC 2013a citing Beckley et al. 2010). This absence of uniformity in sea-level rise is projected to continue throughout the 21st century, though it is *very likely* that sea level will rise in more than 95 percent of the ocean area (IPCC 2014b).

Nationally, relative sea level has been rising at a rate of 1.1 to 2.0 inches per decade along most of the Atlantic and Gulf coasts and more than 3 inches per decade along portions of the Louisiana and Texas coasts (where land subsidence is relatively rapid) (EPA 2021f; Argus et al. 2018; NOAA 2017). Sea level is falling (due to tectonic uplift) at the rate of a few inches per decade in parts of Alaska (EPA 2009, 2021f; Argus et al. 2018; NOAA 2017; National Science and Technology Council 2008). This pattern of relative sea-level rise along the U.S. coast is projected to continue throughout this century (GCRP 2017 citing

Sweet et al. 2017). Tools such as the NOAA Seal Level Rise viewer can be used to understand the impact of coastal inundation under different sea-level rise scenarios along the coastal United States.[16]

Sea-level rise extends the zone of impact of storm surges and waves from tropical and other storms farther inland, causing coastal erosion and other damage. Resulting shoreline erosion is well documented. Since the 1970s, half of the coastal area in Mississippi and Texas has been eroding inland by an average of 2.6 to 3.1 meters (8.5 to 10.2 feet) per year (26 to 31 meters [85 to 102 feet] per decade). In Louisiana, a full 90 percent of the shoreline has been eroding inland at an average rate of more than 12.0 meters (39.4 feet) per year (EPA 2009; Nicholls et al. 2007), with loss of coastal wetlands in the state occurring at a variable rate of 11 to 32 square miles per year from 1932 to 2016 (Couvillion et al. 2017).[17] As sea level continues to rise, so will the likelihood for extensive coastal erosion (GCRP 2017 citing Barnard et al. 2011, Theuerkauf and Rodriguez 2014, and Serafin and Ruggiero 2014).

Precipitation

As the climate warms, evaporation from land and oceans increases and more moisture can be held in the atmosphere (GCRP 2017). Depending on atmospheric conditions, this evaporation causes some areas to experience increases in precipitation events, while other areas are left more susceptible to droughts (Fujita et al. 2019). Average atmospheric water vapor content has increased since at least the 1970s over land and the oceans, and in the upper troposphere, largely consistent with air temperature increases (IPCC 2013a). Because of changes in climate, including increased moisture content in the atmosphere, heavy precipitation events have increased in frequency over most land areas (IPCC 2013a; Min et al. 2011).

The sections that follow discuss global, regional, and national trends in precipitation, droughts, streamflow, and snow cover, respectively.

Precipitation

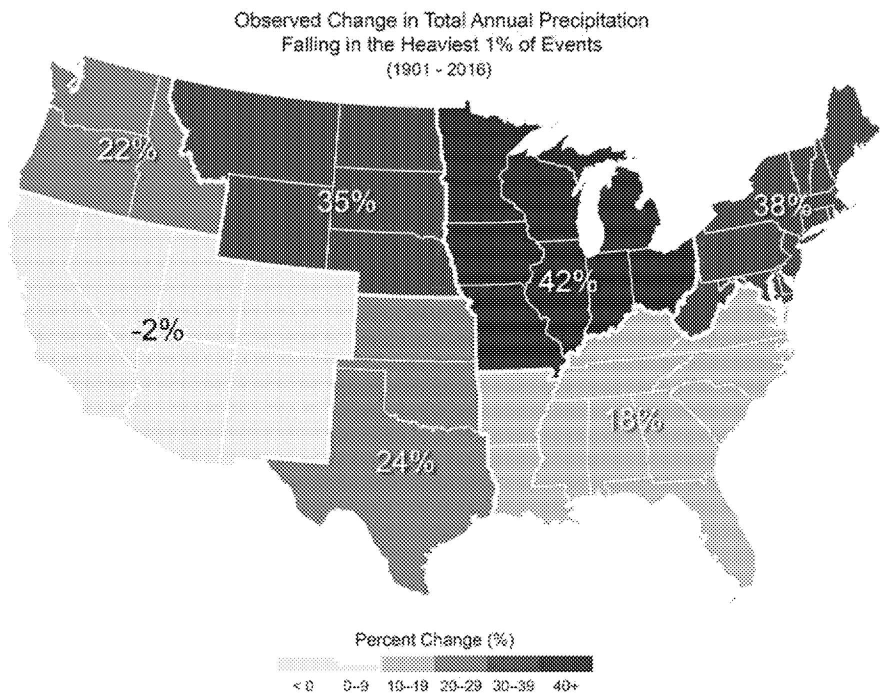
Long-term trends in global precipitation have been observed since 1901. Between 1901 and 2010, increases in precipitation have been observed in the middle and higher latitudes of both the Northern and Southern Hemispheres, specifically in northwestern and eastern parts of North America, parts of Europe and Russia, and southern South America. Drying has been observed in the Sahel region of Africa, the Mediterranean, southern Australia, and parts of Southeast Asia. Spatial and temporal variability for precipitation is high, and data are limited for some regions (IPCC 2013b).

Over the contiguous United States, total annual precipitation increased approximately 4 percent from 1901 to 2016, on average. The greatest increases from 1991 to 2015 (relative to 1901 to 1960) were noted in the Midwest, the Northeast, and the Great Plains, and there were notable decreases in areas of the Southwest (GCRP 2017). Heavy precipitation events also increased in all regions except the Southwest, primarily during the last 3 to 5 decades, with more than a 40 percent increase since 1901 in the Midwest (Figure 5.2.2-5) (GCRP 2017).

[16] NOAA, Office for Coastal Management, DigitalCoast, Sea Level Rise Viewer, https://coast.noaa.gov/digitalcoast/tools/slr.html.

[17] The shoreline erosion in Louisiana is also affected by human alterations and loss of sediment supply (EPA 2009).

Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. Increased Heavy Precipitation Events from 1901 to 2016



Source: GCRP 2018d

In general, climate change is expected to reinforce global precipitation patterns. Under the RCP8.5 scenario, mean precipitation increases in wet regions at high and middle latitudes and the equatorial Pacific, and mean precipitation decreases in dry regions at subtropical and middle latitudes are *likely* by the end of the century (IPCC 2014b).

Drought

Observations of increased dryness since the 1950s suggest that some regions of the world have experienced longer, more intense droughts caused by higher temperatures and decreased precipitation, particularly in the tropics and subtropics (IPCC 2013a). Spatial variability for dryness is high and data availability is limited in some regions from which to draw global conclusions. IPCC concludes that, while there is *likely* increased dryness or drought in East Asia, the Mediterranean, and West Africa, there has *likely* been decreased dryness observed in central North America and Northwest Australia (IPCC 2013a).

Drought trends have been changing for some regions of the United States over the past 50 years (GCRP 2017). Most regions in the United States experienced decreases in drought severity and duration over the 20th century due to increasing average precipitation and the frequency of heavy precipitation events. However, the United States continues to experience severe drought, including in the Southwest from 1999 to 2008 (EPA 2009), Texas and California in 2011 (GCRP 2017), the Midwest in 2012 (GCRP 2017), California in 2014 and 2015 (USGS 2015), and the western United States in 2020 and 2021, which has produced drought conditions in California not seen since 1977 (Carlowicz 2021). According to tree ring data, drought conditions in the western United States over the last decade could represent the driest conditions in 500 years (GCRP 2017).

By the end of the 21st century, it is *likely* that currently dry regions in the world will experience more frequent droughts under RCP8.5 (IPCC 2014b). In southwest North America, where long-term droughts have historically occurred because of natural causes, aridification is projected to increase due to climate change and concomitant general drying and poleward expansion of the subtropical dry zones (IPCC 2013a citing Held and Soden 2006, Seager et al. 2007, and Seager and Vecchi 2010). Twenty-first century drought risk in the southwest and central plains will likely be higher than at any time since at least 1100 CE under both RCP4.5 and RCP8.5, increasing the possibility of megadroughts (droughts lasting 2 decades or more) in these regions (Cook et al. 2015). A more recent study expands upon this concept, showing that the 2000 to 2018 southwestern North America drought was the second driest 19-year period since 800 CE, exceeded only by a late-1500s megadrought, noting that anthropogenic warming increases the probability of otherwise moderate droughts becoming historic megadroughts (Williams et al. 2020).

While current levels of climate change already manifest moderate risks of increased water scarcity, vegetation loss, and wildfire damage, these risks are projected to become more severe with future temperature increases (IPCC 2019b). In addition, increased warming is projected to shift climate zones poleward and increase the amount of land prone to drought (IPCC 2019b).

Streamflow

Melting snow and ice, increased evaporation, and changes in precipitation patterns all affect surface water. Previous assessments indicate variable changes in streamflow and river discharge. The northwest United States has experienced long-term declines in streamflow as a result of declining winter precipitation and, more generally, the western United States has seen recent declines due to drought (GCRP 2017). In contrast, high streamflow is increasing across parts of the Midwest, Mississippi Valley and eastern United States as a result of increases in heavy precipitation (GCRP 2017). Other assessments show even greater global variability in trends, where decreases in streamflow were observed in mainly low- and mid-latitude river basins, while increasing flow at higher latitudes could have resulted from possible permafrost thawing and increased snowmelt (IPCC 2013a). Changes in precipitation have also been identified as a major driver for changing discharge trends across regions (IPCC 2013a).

These streamflow drivers are expected to continue to change throughout the 21st century, with more frequent and intense heavy precipitation events (*high confidence*) and more precipitation falling as rain rather than snow, thereby decreasing snowpack and snowmelt (*high confidence*) in the United States (GCRP 2017). Changes in streamflow are also dominated by snowpack and glacier-fed mountain basins, which are projected to decline and produce earlier spring peak flows (IPCC 2019a).

Snow Cover

Across the Northern Hemisphere, annual mean snow cover decreased 53 percent from 1967 to 2012 (IPCC 2013a). Changes in air temperature, decreased surface albedo, and increased atmospheric water vapor drove a downward trend in maximum snow cover per decade from 1961 to 2015 across North America (GCRP 2017). The amount of snow at the end of the winter season, which is important for water supply provided by snowmelt, has decreased because of springtime warming (GCRP 2017). In addition, North America, Europe, South Asia, and East Asia have experienced a decreasing number of snowfall events; according to IPCC, this is *likely* due to increasing winter temperatures (IPCC 2013a).

Spring snow cover area in the Northern Hemisphere is *likely* to decrease by 7 percent under RCP2.6 and up to 25 percent under RCP8.5 by the end of the 21st century relative to the historical baseline, based on the IPCC multimodel average (IPCC 2014b). Recent studies support these findings, and project that spring snow cover could decrease by as much as 35 percent relative to 1986 to 2005 by the end of the century under RCP8.5 (IPCC 2019a).

Ocean pH

With higher atmospheric CO_2 concentrations in recent decades, oceans have absorbed more CO_2, which lowers the potential of hydrogen (pH[TC "potential of hydrogen (pH" \f A \l "1"])—or increases the acidity—of the water. When CO_2 dissolves in seawater, the hydrogen ion concentration of the water increases; this is measured as a decrease in pH. Compared to the preindustrial period, the pH of the world's oceans has decreased by 0.1 unit (IPCC 2013a). Because pH is measured on a logarithmic scale, this decrease represents a 30 percent increase in the hydrogen ion concentration of seawater, a substantial acidification of the oceans. Although research on the ultimate impacts of declining ocean pH is limited, available observational, laboratory, and theoretical studies indicate that acidification could interfere with the calcification of coral reefs and inhibit the growth and survival of coral reef ecosystems (EPA 2009; GCRP 2017; IPCC 2013a). The Fourth National Climate Assessment notes that, by 2100 under the RCP8.5 emissions scenario, nearly all coral reefs are projected to be surrounded by acidified seawater that will challenge coral growth (GCRP 2017, GCRP 2018a citing Ricke et al. 2013). Further, IPCC projects that, when average global warming reaches 1.3°C (2.3°F) above preindustrial levels, tropical coral reefs are *virtually certain* to experience high risks of impacts such as frequent mass mortalities, and at 2°C (3.6°F), most available evidence (*high agreement, robust evidence*) suggests that coral dominated ecosystems will be nonexistent (IPCC 2013a citing Alvarez-Filip et al. 2009).

The global average surface ocean acidity is projected to increase in acidity (decrease in pH) by 100 to 150 percent by the end of the century under RCP8.5 relative to historical conditions (*high confidence*) (GCRP 2017).

5.2.2.2 Increased Incidence of Severe Weather Events

Tropical cyclones appear to be increasing in intensity since 1970, but no clear trend in the frequency of tropical cyclones each year has been observed. Identifying long-term trends of tropical cyclones has been difficult because observations were limited prior to the satellite era (IPCC 2013a). However, there is observational evidence of an increase in intense tropical cyclone activity correlated with increases of sea-surface temperatures in the North Atlantic, which includes the Gulf Stream, since about 1970 (GCRP 2017). The tracks of tropical cyclones have shifted in a warming climate, migrating toward the poles (GCRP 2017). According to IPCC, while recent assessments indicate that it is *unlikely* that the annual frequency of tropical storms and hurricanes have increased over the past century in the North Atlantic, the increase in intensity since the 1970s in that region is *virtually certain* (IPCC 2013a). Additionally, recent projections indicate that climate change could increase the frequency of the most intense tropical cyclones by the end of the century, but it is still unclear how the overall frequency of events might change (GCRP 2017).

Climate change also causes hurricanes and tropical cyclones to produce heavier precipitation (GCRP 2017). Heavy precipitation events have increased globally since 1951, with some regional and subregional variability (IPCC 2013a). A warmer atmosphere holds more moisture and increases the energy available for convection, causing stronger storms and heavier precipitation (GCRP 2017; Gertler and O'Gorman 2019). The influence of climate change on recent storms is well documented. For example, the rainfall produced in Texas and Louisiana by Hurricane Harvey in 2014 was increased by about 15 to 19 percent due to climate change (Risser and Wehner 2017; van Oldenborgh et al. 2017). Climate change also could increase the probability of a similar extreme event by 17 percent through 2100 relative to the period from 1981 to 2000 under RCP8.5 (Emanuel 2017). Looking forward, tropical cyclone rainfall amounts in the eastern United States could increase by 8 to 17 percent relative to the time period between 1980 and 2006 as a result of a warmer climate (Wright et al. 2015). Evidence is insufficient to determine whether there are trends in large-scale phenomena such as the Atlantic meridional overturning circulation (AMOC), a mechanism for heat transport in the North Atlantic Ocean by which warm waters are carried north and cold waters are carried toward the equator or in small-scale phenomena such as tornadoes, hail, lightning, and dust storms (IPCC 2013a). However, the frequency of weather and climate disasters (including those causing more than $1 billion in damages) has increased in the United States (GCRP 2018a).

Changes in ocean heat content and freshwater-driven buoyancy could potentially weaken the AMOC and, in turn, drive dramatic changes to the regional climates of North America and Europe. However, there is currently *low confidence* in models that show AMOC weakening over the 21st century under a high emissions scenario (RCP8.5) (GCRP 2017). Similarly, confidence in future projections of severe thunderstorms (which includes tornadoes, hail, and winds) is *low* (GCRP 2017).

Climate change is also driving increased wildfire activity. The number of large wildfires in the western United States increased from 1984 to 2011, and area burned by wildfire has been increasing since the 1970s (GCRP 2017). These changes are driven, in part, by changes in climate, such as increasing temperatures, more intense droughts, reduced snowpack, and increased fuel availability and flammability (GCRP 2017, 2018a). Observations of wildfires in western U.S. forests indicate that the area burned by wildfire from 1984 to 2015 was twice what would be expected in the absence of climate change (Abatzoglou and Williams 2016).

Wildfires are projected to further increase in intensity, duration, and frequency under climate change. Projections indicate that for the western United States, large fires will become more of an annual occurrence and very large fires (larger than 50,000 acres) will increase by 2050 under both low and high emissions scenarios (RCP4.5 and RCP8.5) (GCRP 2017). The southeast is also expected to see an increase in wildfires, though with substantial differences between ecoregions (Prestemon et al. 2016). Similarly, Alaska is expected to experience a longer fire season, with a higher risk of severe fires and greater total area burned (GCRP 2017). Wildfires are complex systems, but modeling focused on the climate variables that are closely linked to fire risk (e.g., surface temperature, snowmelt timing) is quite robust and shows that conditions conducive to wildfires are expected to continue into the future under climate change (GCRP 2017).

5.2.2.3 Changes in Ice Cover and Permafrost

Changes in air and ocean temperatures, precipitation onto the ice mass, and water salinity are affecting glaciers, sea-ice cover, and ice sheets. Numerous studies have confirmed that glaciers and ice sheets have shrunk substantially in the past half century. Satellite images have documented the loss of mass from the Greenland ice sheet and the West Antarctic ice sheet (IPCC 2013a; GCRP 2017). Figure 5.2.2-6 shows polar ice sheet mass change from 1992 to 2016.

Since 1979, the annual average Arctic sea-ice area has been declining at a rate of 3.5 to 4.1 percent per decade (IPCC 2013a). Warming in the Arctic has proceeded at about twice the rate as elsewhere, leading to decreases in summer sea-ice extent, glacier and ice sheet mass loss, coastal erosion, and permafrost thawing (IPCC 2013a).[18] Some Arctic ice that previously was thick enough to last through summer has now thinned enough to melt completely in summer. As of 2020, the 12 lowest Arctic sea ice extents in the satellite era occurred in the last 12 years (Kumar et al. 2020a)

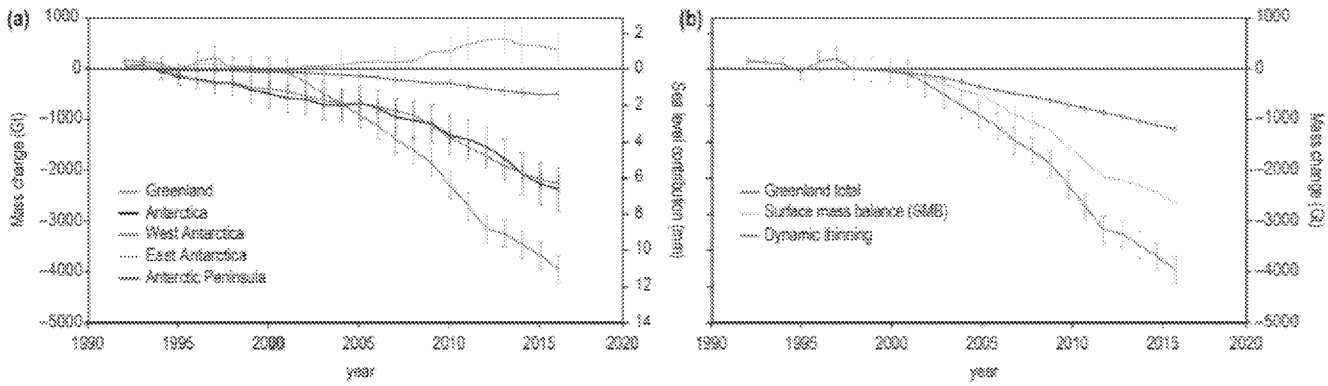
In March 2016, the Arctic experienced the lowest winter maximum ice extent in the satellite record (1979 to 2016), 7 percent below the 1981 to 2010 average (Perovich et al. 2016). Multiyear ice (more than 1 year old) and first-year ice were 22 percent and 78 percent of the ice cover, respectively, compared to 45 percent and 55 percent in 1985 (Perovich et al. 2016). In September 2016, the Arctic sea ice minimum extent was 33 percent lower than the 1981 to 2010 average minimum ice extent, 22 percent larger than the record minimum set in 2012, and tied with 2007 for the second lowest value in the satellite record (1979 to 2016) (Perovich et al. 2016). According to IPCC, average winter sea-ice thickness in the Arctic Basin *likely* decreased by approximately 1.3 and 2.3 meters (4.27 to 7.55 feet) from 1980 to 2008 (IPCC 2013a). The multiyear ice extent (ice that lasts at least two summers) has declined from about 7.9 million square kilometers (3.05 million square miles) in 1980 to as low as 3.5 million square kilometers (1.35 million square miles) in 2012 (IPCC 2013a). These area and thickness reductions allow winds to generate stronger waves, which have increased shoreline erosion along the Alaskan coast. Alaska has also experienced increased thawing of the permafrost base of up to 1.6 inches per year since 1992 (EPA 2009; National Science and Technology Council 2008).

Permafrost top layer temperatures have generally increased since the 1980s (approximately 3°C [5°F] in parts of Alaska and 2°C [3.6°F] in northern Russia), while the depth of seasonally frozen ground has, in some parts of the Eurasian continent, decreased since 1930 by approximately 0.3 meter (1 foot) (IPCC 2013a). The 4°F to 5°F warming in Alaska permafrost has been recorded at a depth of 65 feet (GCRP 2014 citing NRC 2011 and Hawkins and Sutton 2009); at a depth of about 3 feet, the warming has been recorded as 6°F to 8°F (GCRP 2014 citing Hansen and Sato 2012).

The loss of Arctic sea ice is projected to continue throughout the 21st century, and could *very likely* result in nearly sea-ice-free late summers in the Arctic Ocean by the 2040s (*very high confidence*) (GCRP 2017). The Arctic is projected to have approximately a 1 percent chance of having sea-ice-free Septembers after mid-century based on stabilized warming of 1.5°C (2.7°F), and a 10 to 35 percent chance at 2°C (3.6°F) (IPCC 2019a). At the same time, permafrost is projected to continue to decrease, with a switch from continuous to discontinuous permafrost expected over the 21st century (GCRP 2017 citing Vaughan et al. 2013, Grosse et al. 2016, and Schuur et al. 2015). Projections show that by end-of-century, near-surface (within 3 to 4 meters) permafrost could decrease by approximately 24 to 69 percent relative the 1986-to-2005 baseline time period, based on RCP2.6 and RCP8.5, respectively (IPCC 2019a).

[18] Permafrost thawing releases CO_2 and CH_4 into the atmosphere.

Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. Cumulative Ice Sheet Mass Change from 1992 to 2016



Panel (a) shows cumulative mass change and corresponding sea-level rise contributions for different ice sheet regions. Panel (b) shows Greenland Ice Sheet mass change components from surface mass balance (orange) and dynamic thinning (blue) for 2000 to 2016. Uncertainties bars are 1 standard deviation.
Source: IPCC 2019a
Gt = gigatonne
[TC "km2 = kilometers squared" \f A \l "1"]

5.3 Analysis Methods

The methods NHTSA used to characterize the effects of the alternatives on climate have three key elements:

- **Analyzing the impacts of each alternative on GHG emissions.** Many analyses of environmental and energy policies and regulations express their environmental impacts, at least in part, in terms of GHG emissions increases or decreases.
- **Estimating the monetized damages associated with GHG emissions reductions attributable to each alternative.** Economists have estimated the incremental effect of GHG emissions, and monetized those effects, to express the social costs of carbon, CH_4, and N_2O in terms of dollars per ton of each gas. By multiplying the emissions reductions of each gas by estimates of their social cost, NHTSA derived a monetized estimate of the benefits associated with the emissions reductions projected under each action alternative. NHTSA has estimated the monetized damages associated with GHG emissions reductions in its Preliminary Regulatory Impact Analysis (PRIA[TC "Preliminary Regulatory Impact Analysis (PRIA" \f A \l "1"]), as indicated by the CO_2 Damage Reduction Benefit metric in the PRIA benefits and net impacts tables. See Section VI.D. of the PRIA for a description of the methods used for these estimates.
- **Analyzing how GHG emissions reductions under each alternative would affect the climate system (climate effects).** Climate models characterize the relationship between GHG emissions and various climatic parameters in the atmosphere and ocean system, including temperature, precipitation, sea level, and ocean pH.[19] NHTSA translated the changes in GHG emissions associated with each action alternative to changes in temperature, precipitation, sea level, and

[19] In discussing impacts on ocean pH, this SEIS uses both *changes to* and *reductions of* ocean pH to describe ocean acidification. The metric pH is a parameter that measures how acidic or basic a solution is. The increase in atmospheric concentration of CO_2 is causing acidification of the oceans, which can be measured by a decrease in ocean pH.

ocean pH in relation to projections of these climatic parameters under the No Action Alternative.

In this SEIS, impacts on GHG emissions and the climate system are expressed in terms of emissions, CO_2 concentrations, temperature, precipitation, sea level, and ocean pH for each of the alternatives.

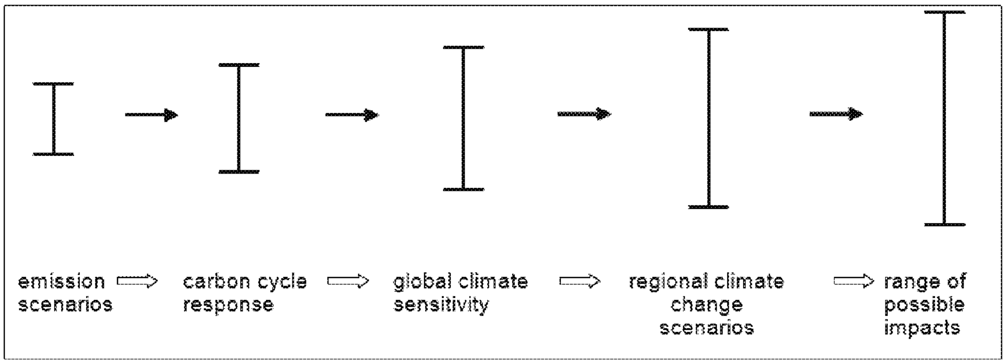
Comparisons between the No Action Alternative and each action alternative are presented to illustrate the different environmental impacts of each alternative. The impact of each action alternative is measured by the difference in the climate parameter (CO_2 concentration, temperature, sea level, precipitation, and ocean pH) under the No Action Alternative and the climate parameter under that action alternative. For example, the reduction in CO_2 emissions attributable to an action alternative is measured by the difference in emissions under the No Action Alternative and emissions under that alternative.

The methods used to characterize emissions and climate impacts consider multiple sources of uncertainty. Sources of uncertainty include the following sources, in addition to many other factors:

- The pace and effects of technology changes in the transportation sector and other sectors that emit GHGs.
- Changes in the future fuel supply and fuel characteristics that could affect emissions.
- Sensitivity of climate to increased GHG concentrations.
- The rate of change in the climate system in response to changing GHG concentrations.
- Potential existence of thresholds in the climate system (which cannot be predicted or simulated).
- Regional differences in the magnitude and rate of climate change.
- Sensitivity to natural variability, such as El Niño conditions.

Moss and Schneider (2000) characterize the “cascade of uncertainty” in climate change simulations (Figure 5.3-1). As indicated in Figure 5.3-1, the emissions estimates used in this SEIS have narrower bands of uncertainty than global climate sensitivity, which is even less uncertain than regional climate change impacts. The impacts on climate are, in turn, less uncertain than the impacts of climate change on affected resources (such as terrestrial and coastal ecosystems, human health, and other resources discussed in Section 8.6.5, *Health, Societal, and Environmental Impacts of Climate Change*). Although the uncertainty bands broaden with each successive step in the analytic chain, not all values within the bands are equally likely; the mid-range values have the highest likelihood.

Figure [STYLEREF 2 \s]-[SEQ Figure * ARABIC \s 3]. Cascade of Uncertainty in Climate Change Simulations



Source: Moss and Schneider 2000

Scientific understanding of the climate system is incomplete; like any analysis of complex, long-term changes to support decision-making, evaluating reasonably foreseeable impacts on the human environment involves many assumptions and uncertainties. This SEIS uses methods and data to analyze climate impacts that represent the best and most current information available on this topic and that have been subjected to extensive peer review and scrutiny. The information cited throughout this section, extracted from the most recent EPA, IPCC, and GCRP reports on climate change, has endured a more thorough and systematic review process than information on virtually any other topic in environmental science and policy. The tools used to perform the climate change impacts analysis, including the Model for the Assessment of Greenhouse Gas-Induced Climate Change (MAGICC)[TC "Model for the Assessment of Greenhouse-Gas Induced Climate Change (MAGICC)" \f A \l "1"] and the Object-Oriented Energy, Climate, and Technology Systems (objECTS[TC "Object-Oriented Energy, Climate, and Technology Systems (objECTS" \f A \l "1"]) version of the Global Change Assessment Model (GCAM[TC "Global Change Assessment Model (GCAM" \f A \l "1"]), are widely available and are commonly used in the scientific community.

The U.S. Climate Change Science Program Synthesis and Assessment Product 3.1 report on the strengths and limitations of climate models (CCSP 2008) provides a thorough discussion of the methodological limitations regarding modeling. Additionally, Chapter 9, Evaluation of Climate Models, of IPCC WGI AR5, provides an evaluation of the performance of global climate models. Readers interested in a detailed treatment of this topic will find the Synthesis and Assessment 3.1 report and Chapter 9 of IPCC WGI AR5 useful in understanding the issues that underpin the modeling of environmental impacts of the Proposed Action and alternatives on climate change.

5.3.1 Methods for Modeling Greenhouse Gas Emissions

This SEIS compares GHG emissions under each action alternative to those under the No Action Alternative. GHG emissions under each alternative were estimated using the methods described in Section 2.3, *Standard-Setting and SEIS Methods and Assumptions*. For years 2020 through 2050, the emissions estimates in this SEIS include GHG emissions from passenger car and light truck fuel combustion (tailpipe emissions) as well as upstream emissions from the production and distribution of fuel. GHG emissions were estimated by the DOT Volpe National Transportation Systems Center (Volpe Center) using the CAFE Compliance and Effects Model (referred to as the CAFE Model), described in Section 2.3.1, *CAFE Model*. To calculate tailpipe CO_2 emissions, the CAFE Model applies estimates of the density and carbon content of gasoline and other fuels. To calculate tailpipe CH_4 and N_2O emissions, the

CAFE Model applies gram-per-mile emission factors Volpe Center staff referenced from EPA's Motor Vehicle Emissions Simulator (MOVES).[20]. To calculate GHG emissions from upstream processes such as refining and electricity generation, the CAFE Model applies process-specific emission factors specified on a gram-per-British thermal unit basis; Volpe Center staff developed these emission factors using the Greenhouse Gases and Regulated Emissions in Transportation (GREET) model, developed by the U.S. Department of Energy (DOE) Argonne National Laboratory.

For the climate analysis, GHG emissions trajectories are projected through the year 2100. In order to estimate GHG emissions for the passenger car and light truck fleets for 2051 to 2100, NHTSA extrapolated from the aforementioned CAFE Model results by applying the projected rate of change in U.S. transportation fuel consumption over this period from GCAM.[21] For 2051 through 2100, the GCAM Reference and GCAM6.0 scenarios project that U.S. road transportation fuel consumption will decline slightly because of assumed improvements in efficiency of internal combustion engine-powered vehicles and increased deployment of noninternal combustion engine vehicles with higher drivetrain efficiencies. However, the projection of road transport fuel consumption beyond 2050 does not change substantially. Therefore, emissions remain relatively constant from 2050 through 2100.[22] The assumptions and methods used to extrapolate GHG emissions estimates beyond 2050 for this SEIS are broadly consistent with those used in the *MY 2011–2015 CAFE Final EIS*, the *MY 2012–2016 CAFE Final EIS* (NHTSA 2010), *Phase 1 Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles Final EIS* (NHTSA 2011), *MY 2017–2025 CAFE Final EIS* (NHTSA 2012), *Phase 2 Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles Final EIS* (NHTSA 2016a), and the *MY 2021–2026 Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule Final EIS* (NHTSA 2020).

The emissions estimates include global CO_2, CH_4, and N_2O emissions resulting from direct fuel combustion and the production and distribution of fuel and electricity (upstream emissions).[23] The MOVES model also estimated non-GHG emissions—both criteria pollutants and air toxics—which are used as inputs in MAGICC6. Criteria pollutants included are: sulfur dioxide (SO_2)[TC "sulfur dioxide (SO2)" \f A \l "1"], nitrogen oxides (NO_X), carbon monoxide (CO[TC "carbon monoxide (CO" \f A \l "1"]), fine particulate matter less than or equal to 2.5 microns in diameter (PM2.5), and volatile organic compounds (VOCs)[TC "volatile organic compounds (VOCs)" \f A \l "1"]. Air toxics included are acetaldehyde, acrolein, benzene, 1,3-butadiene, formaldehyde, and diesel particulate matter less than or equal to 10 microns in diameter.

[20] All downstream emission estimates in the CAFE Model use emission factors from EPA's MOVES3 model version (EPA 2020a).

[21] 2050 is the last year for which the CAFE Model provides estimates of fleet CO_2 emissions for this analysis.

[22] NHTSA anticipates a larger post-2050 decline in passenger car and light truck energy consumption than what is projected in the GCAM Reference scenario due to updated projections around technology availability and adoption, as well as other factors that affect fuel consumption. However, the SEIS approach for projecting emissions from 2051 to 2100 is consistent with methods used in recent NHTSA EISs, conservative in terms of estimating environmental impacts, and reasonable given the uncertainty associated with post-2050 projections.

[23] Upstream emissions considered in this SEIS include those that occur in the United States during the recovery, extraction, and transportation of crude petroleum, as well as during the refining, storage, and distribution of transportation fuels. Emissions from each of these phases of fuel supply are estimated using factors obtained from Argonne's GREET model. A portion of finished motor fuels are refined in the United States using imported crude petroleum as a feedstock, and GREET's emissions factors are used to estimate emissions associated with transporting imported petroleum from coastal port facilities to U.S. refineries, refining it to produce transportation fuels, and storing and distributing those fuels. GREET's emissions factors are also used to estimate domestic emissions from transportation, storage, and distribution of motor fuels that are imported to the United States in refined form.

Fuel savings from more stringent CAFE standards would result in lower overall emissions of CO_2 (the main GHG emitted) because of reduced refining, distribution, and use of transportation fuels.[24] g Fuel efficiency, fuel consumption, and CO_2 emissions are closely connected. Fuel efficiency describes how much fuel a vehicle requires to perform a certain amount of work (for example, how many miles it can travel or how many tons it can carry per mile traveled). A vehicle is more fuel-efficient if it can perform more work while consuming less fuel. Lower fuel consumption reduces CO_2 emissions directly because the primary source of vehicle-related CO_2 emissions is the combustion of carbon-based fuel in internal combustion engines; combustion of a hydrocarbon essentially produces energy (used to power the vehicle), CO_2, and water. Therefore, lowering fuel consumption lowers CO_2 emissions, and greater fuel efficiency means fewer CO_2. emissions.

NHTSA estimated reductions in tailpipe CO_2 emissions resulting from fuel savings by assuming that the carbon content of gasoline, diesel, and other fuels is converted entirely to CO_2 during the combustion process.[25] Specifically, NHTSA estimated CO_2 emissions from fuel combustion as the product of the volume of each type of fuel consumed (in gallons), its mass density (in grams per gallon), the fraction of its total mass represented by carbon (measured as a proportion), and CO_2 emissions per gram of fuel carbon (the ratio of the molecular weights of CO_2 and elemental carbon). NHTSA estimated changes in tailpipe CH_4 and N_2O emissions by applying MOVES-based emission factors for these GHGs to estimated annual mileage accumulation (i.e., VMT) of vehicles of different types and vintages.

Reduced fuel consumption also lowers CO_2 emissions that result from the use of carbon-based energy sources during fuel production and distribution. At the same time, new CAFE standards may also lead to increased CO_2 emissions from processes involved in producing and delivering any alternative energy sources (i.e., other than petroleum) for which consumption increases. In particular, the CAFE Model shows electricity consumption by light-duty vehicles increasing more rapidly under the action alternatives than under the No Action Alternative. NHTSA estimated the CO_2 emissions during each phase of fuel and electricity production and distribution (upstream emissions) using CO_2 emissions rates obtained from the GREET model using previous assumptions about how fuel savings are reflected in reductions in activity during each phase of fuel production and distribution.[26] The total reduction in CO_2 emissions from improving fuel economy under each alternative is the sum of the reductions in motor vehicle emissions from reduced fuel combustion compared to the No Action Alternative plus the reduction in upstream emissions from a lower volume of fuel production and distribution than is projected under the No Action Alternative (minus the increase in upstream emissions resulting from increased electricity generation).

[24] For this rulemaking, NHTSA estimated emissions of vehicular CO_2, CH_4, and N_2O emissions, but did not estimate vehicular emissions of HFCs. HFCs are released to the atmosphere only through air-conditioning system leakage and are not directly related to fuel efficiency. NHTSA's authority under the Energy Policy and Conservation Act, as amended by the Energy Independence and Security Act, extends only to the regulation of vehicle fuel efficiency. For reference, CH_4 and N_2O account for 4 percent of the tailpipe GHG emissions from passenger vehicles and light trucks, and CO_2 emissions account for the remaining 96 percent. Of the total (including non-tailpipe) GHG emissions from passenger cars and light trucks, tailpipe CO_2 represents approximately 97.0 percent, tailpipe CH_4 and N_2O represent approximately 0.6 percent, and HFCs represent approximately 2.4 percent (values are calculated from EPA 2021a).

[25] This assumption results in a slight overestimate of CO_2 emissions, because a small fraction of the carbon content of gasoline is emitted as CO and unburned hydrocarbons. However, the magnitude of this overestimation is likely to be extremely small. This approach is consistent with the recommendation of IPCC for Tier 1 national GHG emissions inventories (IPCC 2006).

[26] Some modifications were made to the estimation of upstream emissions, consistent with NHTSA and EPA assumptions in the NPRM. Section 10.2.3 of the PRIA provides more information regarding these modifications.

5.3.2 Social Cost of Greenhouse Gas Emissions

This SEIS characterizes the potential environmental impacts of the estimated changes in GHG emissions in terms of physical effects, such as changes in temperature and sea level. The PRIA characterizes the monetized social value of these estimated changes in emissions. The social cost of carbon (SC-CO_2[TC "social cost of carbon (SC-CO2" \f A \l "1"]), methane (SC-CH_4[TC "methane (SC-CH4" \f A \l "1"]), or nitrous oxide (SC-N_2O[TC "social cost of nitrous oxide (SC-N2O" \f A \l "1"]) are metrics that estimate the social value of marginal changes in emissions and are expressed in dollars per ton of incremental emissions. Readers may consult the preamble to the proposed rule for a description of how the monetized cost-benefit analysis factors into its decision-making process. The proposed rule preamble and PRIA are both available for public review.

5.3.3 Methods for Estimating Climate Effects

This SEIS estimates and reports the projected reductions in GHG emissions, particularly CO_2, that would result from the alternatives. The reduction in GHG emissions is a direct effect of the increased stringency in passenger car and light truck fuel economy associated with the action alternatives. The reductions in CO_2 emissions, in turn, cause indirect effects on five attributes of climate change: CO_2 concentrations, temperature, sea level, precipitation, and ocean pH.

The subsections that follow describe methods and models used to characterize the reductions in GHG emissions and the indirect effects on the attributes of climate change.

5.3.3.1 MAGICC Modeling

NHTSA used a reduced-complexity climate model (MAGICC) to estimate the changes in CO_2 concentrations and global mean surface temperature, and used increases in global mean surface temperature combined with an approach and coefficients from the IPCC WGI AR5 (IPCC 2013a) to estimate changes in global precipitation. NHTSA used the publicly available modeling software MAGICC6 (Meinshausen et al. 2011) to estimate changes in key direct and indirect effects. NHTSA used MAGICC6 to incorporate the estimated reductions in emissions of CO_2, CH_4, N_2O, CO, NO_X, SO_2, and VOCs and the associated estimated changes in upstream emissions using factors obtained from the GREET model and CAFE Model analysis. NHTSA also performed a sensitivity analysis to examine variations in the direct and indirect climate impacts of the action alternatives under different assumptions about the sensitivity of climate to GHG concentrations in Earth's atmosphere. The results of the sensitivity analysis can be used to infer how the variation in GHG emissions associated with the action alternatives affects the anticipated magnitudes of direct and indirect climate impacts.

The selection of MAGICC for this analysis was driven by several factors:

- MAGICC has been used in the peer-reviewed literature to evaluate changes in global mean surface temperature and sea-level rise. Applications include the IPCC WGI AR5 (IPCC 2013a), where it was used to estimate global mean surface temperature and sea-level rise for simulations of global emissions scenarios that were not run with the more complex atmospheric-ocean general circulation models (AOGCMs) (Meinshausen et al. 2011).[27]

[27] As a reduced-complexity model, MAGICC relies on a more limited number of potential climate and carbon cycle responses and a higher level of parameterization to proxy carbon cycle force than more complex models. Results from MAGICC (e.g.,

- MAGICC is publicly available and was designed for the type of analysis performed in this SEIS.
- More complex AOGCMs are not designed for the type of sensitivity analysis performed in this SEIS and are best used to provide results for groups of scenarios with much greater differences in emissions.
- MAGICC6 uses updated carbon cycle models that can emulate temperature-feedback impacts on the heterotrophic respiration carbon fluxes.
- MAGICC6 incorporates the science from the IPCC WGI AR5; MAGICC 4.1 was used in the *IPCC WGI AR4* (IPCC 2007).[28]

5.3.3.2 Sea-Level Rise

NHTSA estimated the projected changes in global mean sea level based on data from the IPCC WGI AR5 (IPCC 2013a).[29] The sea-level rise analysis uses global mean surface temperature data and projections from 1950 to 2100 and global mean sea-level rise projections from 2010 to 2100. These projections are based on the climate ensemble data of the RCP[30] scenarios for sea level and temperature. Simple equations relating projected changes in sea level to projected changes in temperature are developed for each scenario using a regression model.

The regression models for the RCP4.5 and GCAM6.0 scenarios are developed directly from the RCP4.5 and RCP6.0 data, while the regression model for the GCAM Reference scenario uses a hybrid relation based on the RCP6.0 and RCP8.5 data, as there is no equivalent IPCC scenario. The hybrid relation employs a weighted average of the relationship between RCP6.0 and RCP8.5 sea-level rise and temperature data based on a comparison of the radiative forcings. The temperature outputs of the MAGICC RCP4.5, GCAM6.0, and GCAM Reference simulations are used as inputs to these regression models to project sea-level rise.[31]

5.3.3.3 Ocean pH

NHTSA projected changes in ocean pH using the CO_2 System Calculations (CO2SYS[TC "CO2 System Calculations (CO2SYS" \f A \l "1"]) model, which calculates parameters of the CO_2 system in seawater and freshwater. This model translates levels of atmospheric CO_2 into changes in ocean pH. A lower ocean pH indicates higher ocean acidity, while a higher pH indicates lower acidity.[32] The model was developed by Brookhaven National Laboratory and Oak Ridge National Laboratory and is used by both the U.S. Department of Energy and EPA. Orr et al. (2015) compared multiple ocean carbon system

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projected atmospheric CO_2 concentration in 2100) will, therefore, vary somewhat from those of more complex models (Meinshausen et al. 2011).

[28] Additional capabilities of MAGICC6 as compared to MAGICC 4.1 include a revised ocean circulation model; improved carbon cycle accounting; direct parameterization of black carbon, organic carbon, and ammonia; and updated radiative forcings. Meinshausen et al. 2011 and Wigley et al. 2009 provide further detail on updates from MAGICC 4.1.

[29] Sea-level rise outputs from MAGICC6 were not used, as this component of the model is still under development.

[30] RCP2.6, RCP4.5, RCP6.0, and RCP8.5.

[31] The MAGICC model runs simulations from a preindustrial starting point through the year 2100. Results of this analysis are shown for the years 2040, 2060, and 2100.

[32] Preindustrial average ocean pH was 8.2. The average pH of the world's oceans has decreased by 0.1 unit compared to the preindustrial period, bringing ocean pH to 8.1 (IPCC 2013a).

models and found that the CO2SYS model was more efficient at analyzing observed ocean chemistry data than other models.

This model uses two of four measurable parameters of the CO_2 system (total alkalinity, total inorganic CO_2, pH, and either fugacity or partial pressure of CO_2) to calculate the remaining two input parameters. NHTSA used the CO2SYS model to estimate the pH of ocean water in the year 2040, 2060, and 2100 under the No Action Alternative and each of the action alternatives. For each action alternative, total alkalinity and partial pressure of CO_2 were selected as inputs. The total alkalinity input was held constant at 2,345 micromoles per kilogram of seawater and the projected atmospheric CO_2 concentration (ppm) data was obtained from MAGICC model runs using each action alternative. NHTSA then compared the pH values calculated from each action alternative to the No Action Alternative to determine the impact of the Proposed Action and alternatives on ocean pH.

5.3.3.4 Global Emissions Scenarios

MAGICC uses long-term emissions scenarios that represent different assumptions about key drivers of GHG emissions. The reference scenario used in the direct and indirect analysis for this SEIS is the GCAM Reference scenario (formerly MiniCAM), which does not assume comprehensive global actions to mitigate GHG emissions.[33] NHTSA selected the GCAM Reference scenario for its incorporation of a comprehensive suite of GHG and pollutant gas emissions, including carbonaceous aerosols and a global context of emissions with a full suite of GHGs and ozone precursors. The GCAM Reference scenario is the GCAM representation of a scenario that yields a radiative forcing of approximately 7.0 W/m^2 in the year 2100.

In 2003, CCSP released the *Strategic Plan for the U.S. Climate Change Science Program* (CCSP 2003), which called for the preparation of 21 synthesis and assessment products (SAPs)[TC "synthesis and assessment products (SAPs)" \f A \l "1"] addressing a variety of topics on climate change science, GHG mitigation, and adapting to the impacts of climate change. These scenarios used updated economic and technology data along with improved scenario development tools that incorporated knowledge gained over the years since the *IPCC Special Report on Emissions Scenarios* (IPCC 2000) was released. The strategy recognized that it would be important to have a consistent set of emissions scenarios so that the whole series of SAPs would have the same foundation. Therefore, one of the earliest products in the series—SAP 2.1, Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations and Review of Integrated Scenario Development and Application (Clarke et al. 2007)—developed 15 global emissions scenarios, corresponding to five different emissions trajectories from each of three groups using different models (IGSM, MiniCAM, and MERGE). MiniCAM was later renamed GCAM, which is the updated successor to MiniCAM based on improvements in the modeling, and which is the scenario used in this SEIS.

Each climate-modeling group independently produced a unique emissions reference scenario based on the assumption that no climate policy would be implemented beyond the current set of policies in place using a set of assumptions about drivers such as population changes, economic growth, land and labor productivity growth, technological options, and resource endowments. In addition, each group produced four additional stabilization scenarios, which are defined in terms of the total long-term radiative impact of the suite of GHGs that includes CO_2, N_2O, CH_4, hydrofluorocarbons (HFCs),

[33] For the cumulative analysis, NHTSA used the GCAM6.0 scenario as a reference case global emissions scenario; GCAM6.0 assumes a moderate level of global actions to address climate change. For further discussion, see Section 8.6.2.1, *Global Emissions Scenarios Used for the Cumulative Impact Analysis*.

perfluorocarbons, and sulfur hexafluoride. These stabilization scenarios represent various levels of implementation of global GHG emissions reduction policies.

The results of the direct and indirect impacts analysis rely primarily on the GCAM Reference scenario to represent a reference case emissions scenario. The GCAM Reference scenario provides a global context for emissions of a full suite of GHGs and ozone precursors. NHTSA chose the GCAM Reference scenario to present the results of the direct and indirect effects analysis based on the following factors:

- The GCAM Reference scenario is a slightly updated version of the scenario developed by the MiniCAM model of the Joint Global Change Research Institute, a partnership between Pacific Northwest National Laboratory and the University of Maryland. The GCAM Reference scenario is based on a set of assumptions about drivers such as population, technology, and socioeconomic changes, in the absence of global action to mitigate climate change.
- In terms of global emissions of CO_2 from fossil fuels and industrial sources, the GCAM Reference scenario is an updated version of the MiniCAM model scenario and illustrates a pathway of emissions between the IGSM and MERGE reference scenarios for most of the 21st century. In essence, the GCAM Reference scenario is a middle-ground scenario.
- GCAM Reference was evaluated in CCSP SAP 2.1.

NHTSA and EPA also used the GCAM Reference scenario for the Regulatory Impact Analyses (RIAs) of the Phase 1 and Phase 2 HD National Program Final Rules, as well as the NHTSA and EPA joint final rules that established CAFE and GHG emissions standards for MY 2017–2025 and MY 2021–2026 light-duty vehicle fleets.

The impact of each action alternative was simulated by calculating the difference between annual GHG emissions under the No Action Alternative and emissions under that action alternative and subtracting this change from the GCAM Reference scenario to generate modified global-scale emissions scenarios, which show the effects of the various regulatory alternatives on the global emissions path. For example, CO_2 emissions from passenger cars and light trucks in the United States in 2040 under the No Action Alternative are estimated to be 1,215 million metric tons carbon dioxide ($MMTCO_2$); the emissions in 2040 under Alternative 2 (Preferred Alternative) are estimated to be 1,127 $MMTCO_2$. The difference of 88 $MMTCO_2$ represents the reduction in emissions projected to result from adopting the Preferred Alternative. Global emissions for the GCAM Reference scenario in 2040 are estimated to be 51,701 $MMTCO_2$, and are assumed to incorporate emissions from passenger cars and light trucks in the United States under the No Action Alternative. Therefore, global emissions under the Preferred Alternative are estimated to be 88 $MMTCO_2$ less than this reference level or approximately 51,613 $MMTCO_2$ in 2040. There are some inconsistencies between the overall assumptions that SAP 2.1 and the Joint Global Change Research Institute used to develop the global emissions scenario and the assumptions used in the CAFE Model in terms of economic growth, energy prices, energy supply, and energy demand. However, these inconsistencies affect the characterization of each action alternative in equal proportion, so the relative estimates provide a reasonable approximation of the differences in environmental impacts among the action alternatives.

The forthcoming IPCC Sixth Assessment Report (AR6) will use updated Global Climate Models and GHG concentration scenarios developed for Coupled Model Intercomparison Project Phase 6 (CMIP6). The new GHG concentration scenarios are called Shared Socioeconomic Pathways (SSPs), which will replace the RCPs. SSPs are designed to provide an expanded set of GHG concentrations based on a range of future socioeconomic conditions (Riahi et al. 2017). A set of SSPs provide continuity with RCPs by modeling similar radiative forcing through end of this century (e.g., SSP5-8.5 is a companion to RCP8.5). SSPs also consider a greater range of future aerosol concentrations, which drives a greater range of temperature projections (Riahi et al. 2017).

CMIP6 model ensembles using SSPs yield greater warming and a larger range of projected temperature and precipitation outcomes than CMIP5. Specifically, CMIP6 models project greater warming (by close to 1.5°C [2.7°F]) at the upper end of the 5 percent to 95 percent ensemble envelope for the high SSP5-8.5 scenario, and individual Global Climate Models using SSP5-8.5 simulate warming greater than previously predicted (Tebaldi et al. 2021). CMIP6 models also have larger climate sensitivities than CMIP5 (Zelinka et al. 2020; Hermans et al. 2021), meaning that, on average, CMIP6 models simulate larger global temperature change in response to increases in CO_2 concentrations. For example, effective climate sensitivity corresponding to CO_2 quadrupling increased from 3.7 to 8.4°F in CMIP5 to 3.2 to 10.1°F in CMIP6 (Zelinka et al. 2020).

If the IPCC AR6 SSPs are released in advance of NHTSA's analysis of climate impacts for the Final SEIS for MY 2024–2026 CAFE standards, NHTSA may present in the Final SEIS additional modeling reflecting the action alternatives' climate impacts against the SSPs. Whether NHTSA is able to present such additional climate modeling results will depend on the timing of the release of the SSPs and the availability of datasets compatible with the modeling requirements used in this analysis. The SSPs and underlying data would have to be made publicly available sufficiently in advance of NHTSA's analysis of the alternatives in order for the agency to adjust its modeling method to incorporate the new scenarios and new information into the Final SEIS. Although these SSPs are anticipated to project greater climate-related impacts than the current RCPs (such as climate sensitivities; see Section 5.3.3.6, *Sensitivity Analysis*), preliminary results do not show a significant difference from each scenario's RCP counterpart (e.g., RCP8.5 compared to SSP5-8.5). NHTSA may consider the additional modeling as part of its decision-making process, but it is not anticipated to rise to the level of "significant new circumstances or information" warranting additional supplementation of this Draft SEIS.[34]

5.3.3.5 Reference Case Modeling Runs

The modeling runs and sensitivity analysis simulate relative changes in atmospheric concentrations, global mean surface temperature, precipitation, and sea-level rise that could result under each alternative. The modeling runs are based on the reductions in emissions estimated to result from each of the action alternatives compared to projected emissions under the No Action Alternative. They assume a climate sensitivity of 3°C (5.4°F) for a doubling of CO_2 concentrations in the atmosphere.[35] The approach uses the following four steps to estimate these changes:

1. NHTSA assumed that global emissions under the No Action Alternative would follow the trajectory provided by the global emissions scenario.
2. NHTSA assumed that global emissions for each action alternative would be equal to the global emissions under the No Action Alternative minus the reductions in emissions of CO_2, CH_4, N_2O, SO_2, NO_X, CO, and VOCs estimated to result from each action alternative. For example, the global emissions scenario under Alternative 2 equals the global emissions scenario minus the emissions

[34] 40 CFR § 1502.9(c)(1) (2019).

[35] NHTSA used a climate sensitivity of 3°C, as this is the midpoint of IPCC's estimated range. IPCC states, "the equilibrium climate sensitivity (ECS) is likely in the range 1.5°C to 4.5°C" (IPCC 2013b).

reductions from that alternative. All SO_2 reductions were applied to the Aerosol Region 1 of MAGICC, which includes North America.

3. NHTSA used MAGICC6 to estimate the changes in global CO_2 concentrations, global mean surface temperature, and sea-level rise through 2100 using the global emissions scenario under each alternative developed in steps 1 and 2.
4. NHTSA used the increase in global mean surface temperature to estimate the increase in both global average precipitation and sea-level rise for each alternative using the global emissions scenario.

5.3.3.6 Sensitivity Analysis

NHTSA performed a sensitivity analysis to examine the effect of various equilibrium climate sensitivities on the results. Equilibrium climate sensitivity is the projected responsiveness of Earth's global climate system to increased radiative forcing from higher GHG concentrations and is expressed in terms of changes to global surface temperature resulting from a doubling of CO_2 compared to pre-industrial atmospheric concentrations (278 ppm CO_2) (IPCC 2013a). Sensitivity analyses examine the relationship among the alternatives, likely climate sensitivities, and scenarios of global emissions paths and the associated direct and indirect impacts for each combination.

The IPCC WGI AR5 expresses stronger confidence in some fundamental processes in models that determine climate sensitivity than the AR4 (IPCC 2013a). According to IPCC, with a doubling of the concentration of atmospheric CO_2, there is a *likely* probability of an increase in surface warming in the range of 1.5°C (2.7°F) to 4.5°C (8.1°F) (*high confidence*), *extremely unlikely* less than 1°C (1.8°F) (*high confidence*), and *very unlikely* greater than 6°C (10.8°F) (*medium confidence*) (IPCC 2013a).

NHTSA assessed climate sensitivities of 1.5, 2.0, 2.5, 3.0, 4.5, and 6.0°C (2.7, 3.6, 4.5, 5.4, 8.1, and 10.8°F) for a doubling of CO_2 concentrations in the atmosphere. NHTSA performed the sensitivity analysis around three of the alternatives—the No Action Alternative, Alternative 1, and Alternative 3—because this was deemed sufficient to assess the effect of various climate sensitivities on the results under the range of alternatives considered in this SEIS.

The approach uses the following four steps to estimate the sensitivity of the results to alternative estimates of the climate sensitivity:

1. NHTSA used the GCAM Reference scenario to represent emissions from the No Action Alternative.
2. Starting with the respective GCAM scenario, NHTSA assumed that the reductions in global emissions of CO_2, CH_4, N_2O, SO_2, NO_X, CO, and VOCs resulting from the least stringent alternative (Alternative 1) would be equal to the global emissions of each pollutant under the No Action Alternative minus emissions of each pollutant under Alternative 1. Separately, NHTSA used the same approach for Alternative 3 (the lowest GHG emissions alternative) as compared to the No Action Alternative.[36] All SO_2 reductions were applied to Aerosol Region 1 of MAGICC, which includes North America.

[36] Some SO_2 emissions are associated with the charging of EVs. However, total power plant emissions are limited by "caps" under the EPA Acid Rain Program and the Cross-State Air Pollution Rule, and will be reduced through emissions standards such as the Mercury and Air Toxics Standards rule. Because of these rules and advances in technology, emissions from the power-generation sector are expected to decline over time (the grid is expected to become cleaner). Any economic activity or trend that leads to an increase in electrical demand—including increases in electric vehicle sales and use—would be accommodated by the power industry in planning for compliance with applicable emissions limitations.

3. NHTSA assumed a range of climate sensitivity values consistent with the 10 to 90 percent probability distribution from the IPCC WGI AR5 (IPCC 2013a) of 1.5, 2.0, 2.5, 3.0, 4.5, and 6.0°C (2.7, 3.6, 4.5, 5.4, 8.1, and 10.8°F).
4. For each climate sensitivity value in Step 3, NHTSA used MAGICC6 to estimate the resulting changes in CO_2 concentrations and global mean surface temperature, as well as the regression-based analysis to estimate sea-level rise through 2100 for the global emissions scenarios in Steps 1 and 2.

Section 5.4, *Environmental Consequences*, presents the results of the model runs for the alternatives. For the direct and indirect impacts analysis, the sensitivity analysis was performed against the GCAM Reference scenario (789 ppm in 2100).

5.3.4 Tipping Points and Abrupt Climate Change

The term *tipping point* is most typically used, in the context of climate change, to describe situations in which the climate system (the atmosphere, hydrosphere, land, cryosphere, and biosphere) reaches a point at which a disproportionally large or singular response in a climate-affected system occurs as a result of a moderate additional change in the inputs to that system (such as an increase in the CO_2 concentration). Exceeding one or more tipping points, which "occur when the climate system is forced to cross some threshold, triggering a transition to a new state at a rate determined by the climate system itself and faster than the cause" (EPA 2009 citing NRC 2002), could result in abrupt changes in the climate or any part of the climate system. Abrupt climate changes could occur so quickly and unexpectedly that human systems would have difficulty adapting to them (EPA 2009 citing NRC 2002).

NHTSA's assessment of tipping points and abrupt climate change is largely based on an analysis of recent climate change science synthesis reports: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC 2013a), *Climate Change Impacts in the United States: The Third National Climate Assessment* (GCRP 2014), and *Climate Science Special Report: Fourth National Climate Assessment, Volume 1* (GCRP 2017). The analysis identifies vulnerable systems, potential thresholds, and estimates of the causes, likelihood, timing, and impacts of abrupt climate events.

Although there are methodological approaches to estimate changes in temperatures resulting from a reduction in GHG emissions and associated radiative forcing, the current state of science does not allow for quantifying how reduced emissions from a specific policy or action might affect the probability and timing of abrupt climate change. This area of climate science is one of the most complex and scientifically challenging. Given the difficulty of simulating the large-scale processes involved in these tipping points, or inferring their characteristics from paleoclimatology, considerable uncertainties remain on tipping points and the rate of change. Despite the lack of a precise quantitative methodological approach, NHTSA has provided a qualitative and comparative analysis of tipping points and abrupt climate change in Chapter 8, *Cumulative Impacts,* Section 8.6.5.2, *Sectoral Impacts of Climate Change*, under *Tipping Points and Abrupt Climate Change*. The analysis applies equally to direct and indirect impacts, as well as to cumulative impacts.

5.4 Environmental Consequences

This section describes projected impacts on climate under the Proposed Action and alternatives relative to the No Action Alternative. NHTSA has identified Alternative 2 as the Preferred Alternative. Using the methods described in Section 5.3, *Analysis Methods*, NHTSA modeled the direct and indirect impacts of the alternatives on atmospheric CO_2 concentrations, temperature, precipitation, sea level, and ocean pH. This analysis is based on a scenario under which no other major global actions would reduce GHGs (i.e., the current climate trajectory, independent of other actions). The analysis of cumulative impacts can be found in Chapter 8, *Cumulative Impacts.*

In summary, each of the action alternatives would result in reduced GHG emissions compared with the No Action Alternative. The more an alternative would decrease GHG emissions, the more it would be expected to decrease the direct and indirect climate change impacts associated with such emissions.

5.4.1 Greenhouse Gas Emissions

Using the methods described in Section 5.3, *Analysis Methods*, NHTSA estimated projected emissions reductions under the action alternatives for 2021 through 2100. These emissions reductions represent the differences in total annual emissions in future years of U.S. passenger cars and light trucks in use under the No Action Alternative and each action alternative. The projected change in fuel production and use under each alternative determines the resulting impacts on total energy use and petroleum consumption, which, in turn, determine the reduction in CO_2 emissions under each alternative. Because CO_2 accounts for such a large fraction of total GHGs emitted during fuel production and use—more than 96 percent, even after accounting for the higher GWPs of other GHGs—NHTSA's consideration of GHG impacts focuses on reductions in CO_2 emissions expected under the Proposed Action and alternatives. However, in assessing the direct and indirect impacts and cumulative impacts on climate change indicators (i.e., global average surface temperature, sea level, precipitation, and ocean pH, as described in Section 5.4.2, *Direct and Indirect Impacts on Climate Change Indicators*, and Section 8.6.4, *Cumulative Impacts on Greenhouse Gas Emissions and Climate Change*), NHTSA incorporates reductions of all GHGs by the nature of the models used to project changes in the relevant climate indicators.

Table 5.4.1-1 and Figure 5.4.1-1 show total U.S. passenger car and light truck CO_2 emissions under the No Action Alternative and emissions reductions that would result from the Proposed Action and alternatives from 2021 to 2100. All action alternatives would result in lower CO_2 emissions than the No Action Alternative because all action alternatives involve more stringent CAFE standards than the No Action Alternative. U.S. passenger car and light truck emissions from 2021 to 2100 would range from a low of 81,000 $MMTCO_2$ under Alternative 3 to a high of 89,600 $MMTCO_2$ under the No Action Alternative. Compared to the No Action Alternative, projected emissions reductions from 2021 to 2100 under the action alternatives would range from 4,100 to 8,600 $MMTCO_2$. Compared to total global emissions of 4,950,865 $MMTCO_2$ over this period (projected by the GCAM Reference scenario), this rulemaking is expected to reduce global CO_2 emissions by approximately 0.08 to 0.17 percent from projected levels under the No Action Alternative.

Table [STYLEREF 3 \s]-[SEQ Table * ARABIC \s 3]. Carbon Dioxide Emissions and Emissions Reductions($MMTCO_2$) from All Passenger Cars and Light Trucks, 2021–2100, by Alternative[a]

Alternative	Total Emissions	Emissions Reductions Compared to No Action	Percent (%) Emissions Reductions Compared to No Action Alternative Emissions
Alt. 0 (No Action)	89,600	-	-
Alt. 1	85,500	4,100	5%
Alt. 2	83,200	6,400	7%
Alt. 3	81,000	8,600	10%

Notes:
[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact differences between the values.
$MMTCO_2$ = million metric tons of carbon dioxide

Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. Carbon Dioxide Emissions and Emissions Reductions ($MMTCO_2$) from All Passenger Cars and Light Trucks, 2021 to 2100, by Alternative

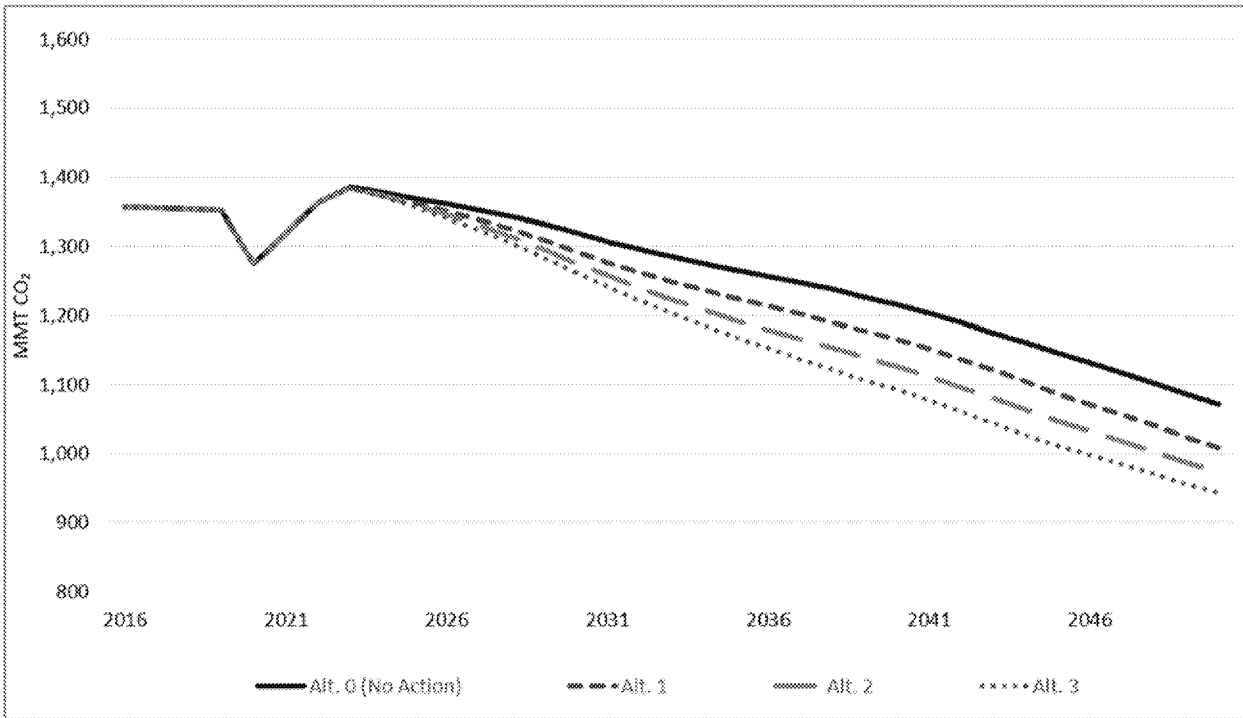
OBJ

$MMTCO_2$ = million metric tons of carbon dioxide

To get a sense of the relative magnitude of these reductions, it can be helpful to consider emissions from passenger cars and light trucks in the context of emissions projections from the transportation sector. Passenger cars and light trucks currently account for 20 percent of CO_2 emissions in the United States. The action alternatives would reduce total CO_2 emissions from U.S. passenger cars and light trucks by a range of 5 to 10 percent from 2021 to 2100 compared to the No Action Alternative. Compared to annual U.S. CO_2 emissions of 7,193 $MMTCO_2$ from all sources by the end of the century projected by the GCAM Reference scenario (Thomson et al. 2011), the action alternatives would reduce total U.S. CO_2 emissions in the year 2100 by a range of 0.8 to 1.6 percent.[37] Figure 5.4.1-2 shows the projected annual emissions from U.S. passenger cars and light trucks under the alternatives.

[37] Fuel consumption data is held constant after 2095, as this is the last year emissions data are available from GCAM Reference.

Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. Projected Annual Carbon Dioxide Emissions ($MMTCO_2$) from All Passenger Cars and Light Trucks by Alternative



$MMTCO_2$ = million metric tons of carbon dioxide

Table 5.4.1-2 also illustrates that the Proposed Action and alternatives would reduce passenger car and light truck emissions of CO_2 from their projected levels under the No Action Alternative. Similarly, under the Proposed Action and alternatives, CH_4 and N_2O emissions in future years are projected to decline from their projected levels under the No Action Alternative. These reductions are presented in CO_2 equivalents ($MMTCO_2e$) in the table below. All action alternatives would result in emissions reductions compared to the No Action Alternative. Of all the action alternatives, Alternative 3 would result in the greatest emissions reductions.

Table [STYLEREF 3 \s]-[SEQ Table * ARABIC \s 3]. Emissions of Greenhouse Gases ($MMTCO_2e$ per year) from All Passenger Cars and Light Trucks by Alternative[a]

GHG and Year	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
Carbon dioxide (CO_2)				
2020	1,275	1,275	1,275	1,275
2040	1,215	1,165	1,127	1,093
2060	1,065	1,003	972	940
2080	1,058	996	965	933
2100	984	927	897	868
Methane (CH_4)				
2020	39	39	39	39
2040	37	36	35	34
2060	34	32	31	30
2080	34	32	31	30
2100	31	30	29	28
Nitrous oxide (N_2O)				
2020	14	14	14	14
2040	11	11	11	10
2060	10	9	9	9
2080	10	9	9	8
2100	9	8	8	8
Total (all GHGs)				
2020	1,328	1,328	1,328	1,328
2040	1,264	1,212	1,173	1,137
2060	1,109	1,044	1,012	979
2080	1,101	1,037	1,005	972
2100	1,024	965	934	904

Notes:
[a] Emissions from 2051 to 2100 were scaled using the rate of change for the U.S. transportation fuel consumption from the GCAM Reference scenario. These assumptions project a slight decline over this period.
$MMTCO_2e$ = million metric tons carbon dioxide equivalent

5.4.1.1 Comparison to the U.S. Greenhouse Gas Targets Submitted to the United Nations Framework Convention on Climate Change

These results can be viewed in light of U.S. GHG emissions reduction targets. On April 22, 2021, President Biden submitted a "Nationally Determined Contribution" (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC), with a target for the United States to achieve a 50 to 52 percent reduction in economy-wide net GHG pollution from 2005 levels by 2030. This target was submitted under the Paris Agreement under the UNFCCC, which entered into force on November 4,

2016. The United States formally withdrew from the Paris Agreement in November 2020, and officially rejoined the Paris Agreement in February 2021.[38]

Total GHG emissions from U.S. passenger cars and light trucks in 2030 are projected to be below 2005 levels for the No Action and action alternatives. The percentage decreases range from a 4.5 percent reduction for the No Action Alternative to an 8.7 percent reduction for the most stringent alternative (Alternative 3). These reductions in emissions alone would not reduce total passenger car and light truck vehicle emissions to a 50 to 52 percent reduction from 2005 levels by 2030.

However, the Energy Policy and Conservation Act, as amended by the Energy Independence and Security Act, requires NHTSA to continue setting fuel economy standards for MYs 2027–2030, which can further contribute to meeting the U.S. target. In addition, the President's targets outlined above do not specify that every emitting sector of the economy must contribute equally proportional emissions[XE "emissions"] reductions. Thus, smaller emissions reductions in the passenger car and light truck sector could be compensated for by larger reductions in other sectors. In addition, the action of setting fuel economy standards[XE "standards"] does not directly regulate total emissions from vehicles. NHTSA's authority to promulgate CAFE standards does not allow the agency to regulate other mobile sources of GHG emissions (e.g., HFC emissions from vehicle air conditioners) or other factors affecting transportation emissions, such as driving habits or use trends; NHTSA cannot, for example, control VMT[TC "VMT" \f A \l "1"]. Under all of the alternatives, growth in the number of passenger cars and light trucks in use throughout the United States, combined with assumed increases in their average use (annual VMT per vehicle) due to economic improvement and a variety of other factors, is projected to result in growth in passenger car and light truck VMT, peaking in 2045 and declining gradually in the following years. While NHTSA does not have the authority to regulate VMT, the DOT is investing in efforts to reduce VMT to help the United States meet its emissions reductions targets. These efforts include investing in smart cities and public transportation improvements.

This projected growth in travel between 2020 and 2045 offsets some of the effect of increased passenger car and light truck fuel economy[XE "fuel efficiency"] under the action alternatives, due to increases in U.S. transportation fuel consumption[XE "fuel consumption"] from vehicles. Despite expected growth in travel, CO_2 emissions are projected to decrease mainly due to a rise in average miles per gallon for all passenger cars and light trucks in use resulting from older, less efficient, vehicles being replaced by newer, more efficient, models over time. The projected decrease in CO_2 emissions highlights how this rulemaking is an important component of a variety of actions in various sectors to meet the U.S. GHG targets stated in the United States' NDC.

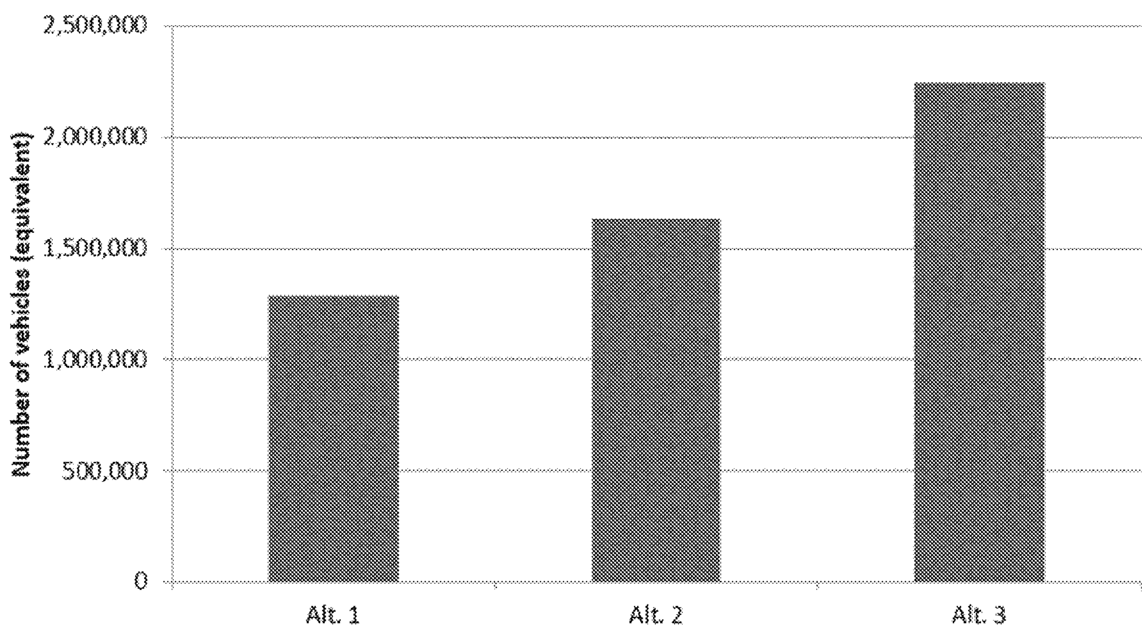
5.4.1.2 Comparison to Annual Emissions from Passenger Cars and Light Trucks

As an illustration of the fuel use projected under the Proposed Action and alternatives, Figure 5.4.1-3 expresses the CO_2 reductions under each action alternative in 2025 as the equivalent number of passenger cars and light trucks that would produce those emissions in that year. The emissions

[38] United Nations. January 20, 2021. Paris Agreement Instrument of Acceptance: United States of America. Available at [HYPERLINK "https://treaties.un.org/doc/Publication/CN/2021/CN.10.2021-Eng.pdf"]; U.S. Department of State. Press Statement. February 19, 2021. Anthony J. Blinken, Secretary of State. "The United States Officially Rejoins the Paris Agreement". Available at [HYPERLINK "https://www.state.gov/the-united-states-officially-rejoins-the-paris-agreement/" \l ":~:text=On%20January%2020%2C%20on%20his,back%20into%20the%20Paris%20Agreement"].

reductions under the action alternatives would be equivalent to the annual emissions from 1,284,000 passenger cars and light trucks (Alternative 1) to 2,248,000 passenger cars and light trucks (Alternative 3) in 2025, compared to the annual emissions that would occur under the No Action Alternative. A total number of 253,949,000 passenger cars and light trucks are projected to be on the road in 2025 under the No Action Alternative.[39,40]

Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. Number of Passenger Cars and Light Trucks Equivalent to Carbon Dioxide Reductions in 2025 Compared to the No Action Alternative



5.4.1.3 Global Carbon Budget

In response to public comments received on prior NHTSA EISs, the agency has considered the GHG impacts of its fuel economy actions in terms of a global carbon "budget." This budget is an estimate for the total amount of anthropogenic CO_2 that can be emitted to have a certain chance of limiting the global average temperature increase to below 2°C (3.6°F) relative to preindustrial levels. IPCC estimates that if cumulative global CO_2 emissions from 1870 onwards are limited to approximately 1,000 Gigatonnes (Gt[TC "Gigatonnes (Gt" \f A \l "1"]) C (3,670 Gt CO_2), then the probability of limiting the temperature increase to below 2°C (3.6°F) is greater than 66 percent (IPCC 2013b). It should be noted that since this report was published, various studies have produced estimates of the remaining global carbon budget; some estimates have been larger (Millar et al. 2017) and others have been smaller (Lowe and Bernie 2018). These estimates vary depending on a range of factors, such as the assumed conditions

[39] Values for vehicle totals have been rounded.

[40] The passenger car and light truck equivalency is based on an average per-vehicle emissions estimate, which includes both tailpipe CO_2 emissions and associated upstream emissions from fuel production and distribution. The average passenger car and light truck is projected to account for 5.39 metric tons of CO_2 emissions in 2025 based on MOVES, the GREET model, and EPA analysis.

and the climate model used (Rogelj et al. 2019). Because of underlying uncertainties and assumptions, no one number for the remaining global carbon budget can be considered definite.

Using the IPCC estimated carbon budget, as of 2011[41], approximately 51 percent, or 515 Gt C (1,890 Gt CO_2), of this budget had already been emitted, leaving a remaining budget of 485 Gt C (1,780 Gt CO_2) (IPCC 2013b). From 2011 to 2019, CO_2 emissions from fossil fuels, cement production, and land-use change totaled approximately 101 Gt C (370 Gt CO_2), leaving a remaining budget from 2020 onwards of 384 Gt C (1,406 Gt CO_2) (CDIAC 2020).[42] Under the No Action Alternative, U.S. passenger cars and trucks are projected to emit 24 Gt C (90 Gt CO_2) from 2021 to 2100, or 6.0 percent of the remaining global carbon budget. Under Alternative 3, this projection decreases to 22 Gt C (81 Gt CO_2) or 5.4 percent of the remaining budget.

The emissions reductions necessary to keep global emissions within this carbon budget must include, but could not be achieved solely with drastic reductions in emissions from the U.S. passenger car and light truck vehicle fleet and would also require drastic reductions in all U.S. sectors and from the rest of the developed and developing world. Even with the full implementation of global emissions reduction commitments to date, global emissions in 2030 would still be roughly 15 $GtCO_2e$ higher than what is consistent with a scenario that limits warming to 2°C [3.6°F] from preindustrial levels (United Nations Environment Programme 2020).

In addition, achieving GHG reductions from the passenger car and light truck vehicle fleet to the same degree that emissions reductions will be needed globally to avoid using all of the carbon budget would require substantial increases in technology innovation and adoption compared to today's levels and would require the economy and the vehicle fleet to substantially move away from the use of fossil fuels.

5.4.2 Direct and Indirect Impacts on Climate Change Indicators

The direct and indirect impacts of the Proposed Action and alternatives on five relevant climate change indicators are described in Section 5.4.2.1, *Atmospheric Carbon Dioxide Concentrations*, and Section 5.4.2.2, *Climate Change Attributes*. Section 5.4.2.3, *Climate Sensitivity Variations*, presents the sensitivity analysis. The impacts of the Proposed Action and alternatives on global mean surface temperature, atmospheric CO_2 concentrations, precipitation, sea level, and ocean pH would be small compared to the expected changes associated with the emissions trajectories in the GCAM Reference scenario. This is due primarily to the global and multi-sectoral nature of climate change. Although these effects are small, they occur on a global scale and are long-lasting. More importantly, these reductions play an important role in national and global efforts to reduce GHG emissions across a wide range of sources. The combined impact of the emissions reductions associated with the Proposed Action and alternatives with emissions reductions from other sources could have large health, societal, and environmental impacts. Finally, NHTSA is required by the Energy Independence and Security Act to set standards for

[41] NHTSA intends to update this analysis to reflect the most recent carbon budget once IPCC's Sixth Assessment Report (AR6) is released.

[42] Factoring in non-CO_2 influences on the climate, the global carbon budget is approximately 790 Gt C (2,900 Gt CO_2). As of 2011, approximately 65 percent, or 515 Gt C (1,890 Gt CO_2) of this budget had already been emitted, leaving a remaining budget of 275 Gt C (1,010 Gt CO_2) (IPCC 2013b). From 2011 to 2019, CO_2 emissions from fossil fuels, cement production, and land-use change totaled approximately 101 Gt C, leaving a remaining budget from 2020 onwards of 174 Gt C, including non-CO_2 influences (CDIAC 2020).

MYs 2027–2030, standards that are likely to be more stringent than Alternative 2 and produce additional GHG reductions.

MAGICC6 is a reduced-complexity climate model well calibrated to the mean of the multimodel ensemble results for four of the most commonly used emissions scenarios—RCP2.6 (low), RCP4.5 (medium), RCP6.0 (medium-high), and RCP8.5 (high) from the IPCC RCP series—as shown in Table 5.4.2-1.[43] As the table shows, the results of the model runs developed for this analysis agree relatively well with IPCC estimates for both CO_2 concentrations and surface temperature.

Table [STYLEREF 3 \s]-[SEQ Table * ARABIC \s 3]. Comparison of MAGICC Modeling Results and Reported IPCC Results[a]

Scenario	CO_2 Concentration (ppm)		Global Mean Increase in Surface Temperature (°C)	
	IPCC WGI (2100)	MAGICC (2100)	IPCC WGI (2081–2100)	MAGICC (2100)
RCP2.6	421	426	1.0	1.1
RCP4.5	538	544	1.8	2.1
RCP6.0	670	674	2.2	2.6
RCP8.5	936	938	3.7	4.2

Source: IPCC 2013b
Notes:
[a] The IPCC values represent the average of the 5 to 95 percent range of global mean surface air temperature.
ppm = parts per million; °C = degrees Celsius; MAGICC = Model for the Assessment of Greenhouse-gas Induced Climate Change; IPCC = Intergovernmental Panel on Climate Change; RCP = Representative Concentration Pathways; WGI = Working Group 1

As discussed in Section 5.3.1, *Methods for Modeling Greenhouse Gas Emissions*, NHTSA used the GCAM Reference scenario to represent the No Action Alternative in the MAGICC modeling runs. CO_2 concentrations under the No Action Alternative are 789.11 ppm and range from 788.74 under Alternative 1 to 788.33 ppm under Alternative 3 in 2100 (Table 5.4.2-2). For 2040 and 2060, the corresponding range of ppm differences across alternatives is even smaller. Because CO_2 concentrations are the key determinant of other climate effects (which in turn drive the resource impacts discussed in Section 8.6, *Cumulative Impacts—Greenhouse Gas Emissions and Climate Change*), this leads to very small differences in these effects.

Table [STYLEREF 3 \s]-[SEQ Table * ARABIC \s 3]. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increase, Sea-Level Rise, and Ocean pH (GCAM Reference) by Alternative[a]

	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b, c]			Sea-Level Rise (cm)[b, d]			Ocean pH[e]		
	2040	2060	2100	2040	2060	2100	2040	2060	2100	2040	2060	2100
Totals by Alternative												
Alt. 0 (No Action)	479.04	565.44	789.11	1.287	2.008	3.484	22.87	36.56	76.28	8.4099	8.3476	8.2176
Alt. 1	478.99	565.29	788.74	1.287	2.007	3.483	22.87	36.56	76.25	8.4099	8.3477	8.2178
Alt. 2	478.96	565.19	788.52	1.287	2.007	3.482	22.87	36.55	76.23	8.4100	8.3478	8.2179

[43] NHTSA used the MAGICC default climate sensitivity of 3.0 °C (5.4 °F).

	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b, c]			Sea-Level Rise (cm)[b, d]			Ocean pH[e]		
	2040	2060	2100	2040	2060	2100	2040	2060	2100	2040	2060	2100
Alt. 3	478.93	565.11	788.33	1.287	2.007	3.481	22.87	36.55	76.22	8.4100	8.3478	8.2180
Reductions Under Proposed Action and Alternatives												
Alt. 1	0.05	0.15	0.37	0.000	0.001	0.002	0.00	0.01	0.03	-0.0000	-0.0001	-0.0002
Alt. 2	0.08	0.25	0.58	0.000	0.001	0.002	0.00	0.01	0.05	-0.0001	-0.0002	-0.0003
Alt. 3	0.11	0.33	0.77	0.001	0.002	0.003	0.00	0.01	0.06	-0.0001	-0.0002	-0.0004

Notes:
[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions and increases might not reflect the exact difference of the values in all cases.
[b] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986 to 2005.
[c] Temperature changes reported as 0.000 are more than zero but less than 0.001.
[d] Sea-level rise changes reported as 0.00 are more than zero but less than 0.01.
[e] Ocean pH changes reported as 0.0000 are less than zero but more than -0.0001.
CO_2 = carbon dioxide; °C = degrees Celsius; ppm = parts per million; cm = centimeters; GCAM = Global Change Assessment Model

5.4.2.1 Atmospheric Carbon Dioxide Concentrations

As Figure 5.4.2-1 and Figure 5.4.2-2 show, the reduction in projected CO_2 concentrations under the Proposed Action and alternatives compared to the No Action Alternative amounts to a very small fraction of the projected total increases in CO_2 concentrations. However, the relative impact of the Proposed Action and alternatives is demonstrated by the reduction in the rise of CO_2 concentrations under the range of action alternatives. As shown in Figure 5.4.2-2, the reduction in CO_2 concentrations by 2100 under Alternative 3 compared to the No Action Alternative is nearly twice that of Alternative 1.

Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. Atmospheric Carbon Dioxide Concentrations by Alternative

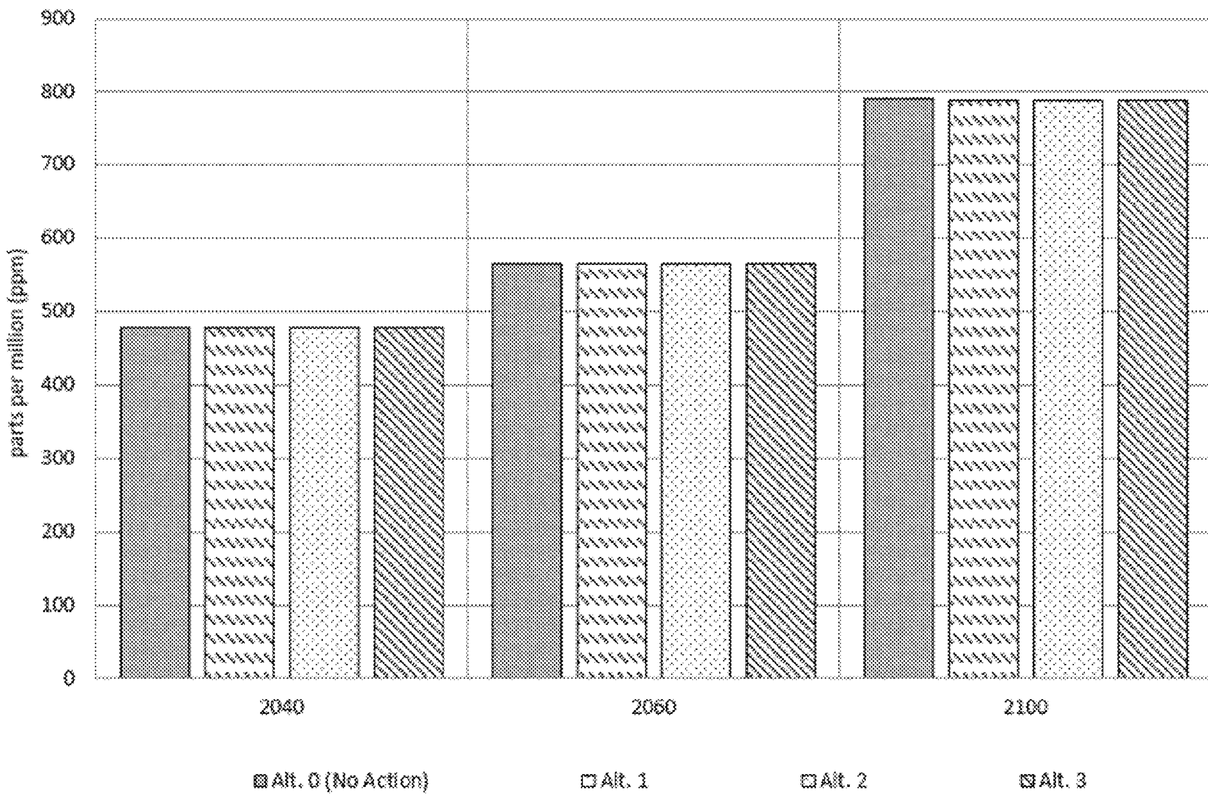
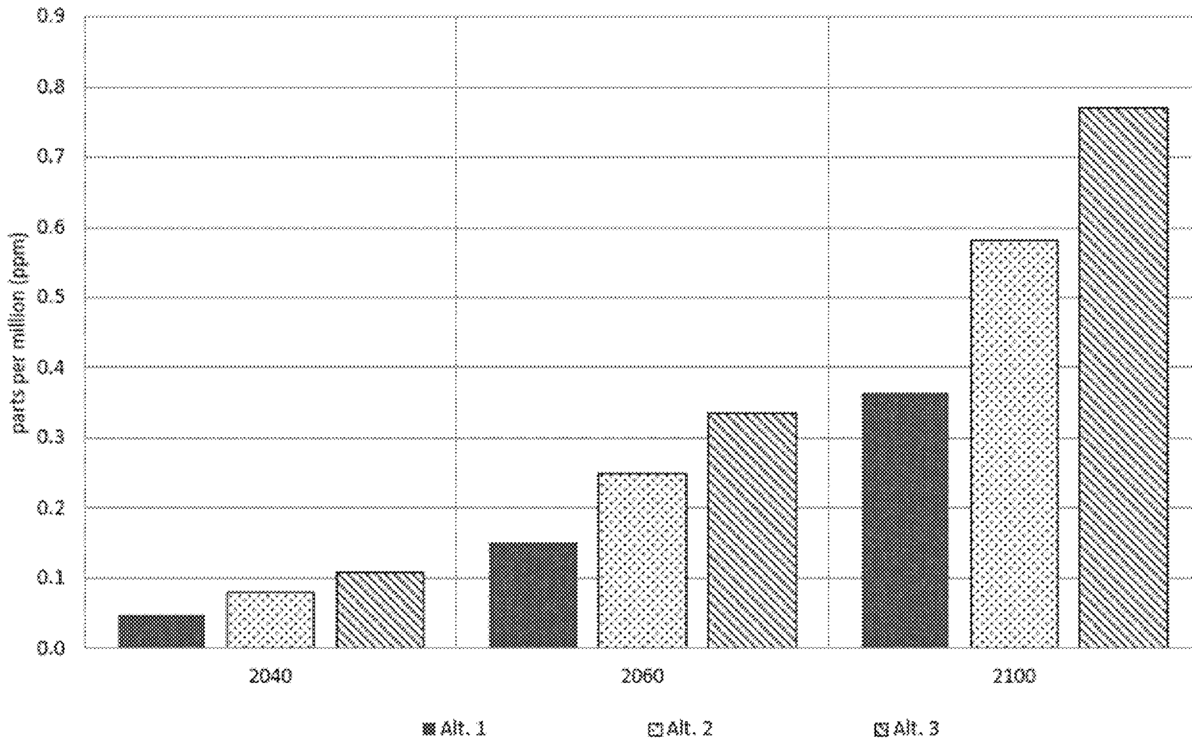


Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. Reductions in Atmospheric Carbon Dioxide Concentrations Compared to the No Action Alternative



5.4.2.2 Climate Change Attributes

Temperature

Table 5.4.2-2 lists MAGICC simulations of mean global surface air temperature increases. Under the No Action Alternative in all analyses, global surface air temperature is projected to increase from 1986 to 2005 average levels by 1.29°C (2.32°F) by 2040, 2.01°C (3.61°F) by 2060, and 3.48°C (6.27°F) by 2100.[44] The differences among the reductions in baseline temperature increases projected to result from the various action alternatives are small compared to total projected temperature increases, which are shown in Figure 5.4.2-3. For example, in 2100 the reduction in temperature rise compared to the No Action Alternative ranges from 0.002°C (0.003°F) under Alternative 1 to 0.003°C (0.006°F) under Alternative 3.

[44] Because the actual increase in global mean surface temperature lags the "commitment to warming" (i.e., continued warming from GHGs that have already been emitted to date, because of the slow response of the climate system), the impact on global mean surface temperature increase is less than the impact on the long-term commitment to warming. The actual increase in surface temperature lags the commitment due primarily to the time required to heat the ocean to the level committed by the concentrations of the GHGs.

Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. Global Mean Surface Temperature Increase by Alternative

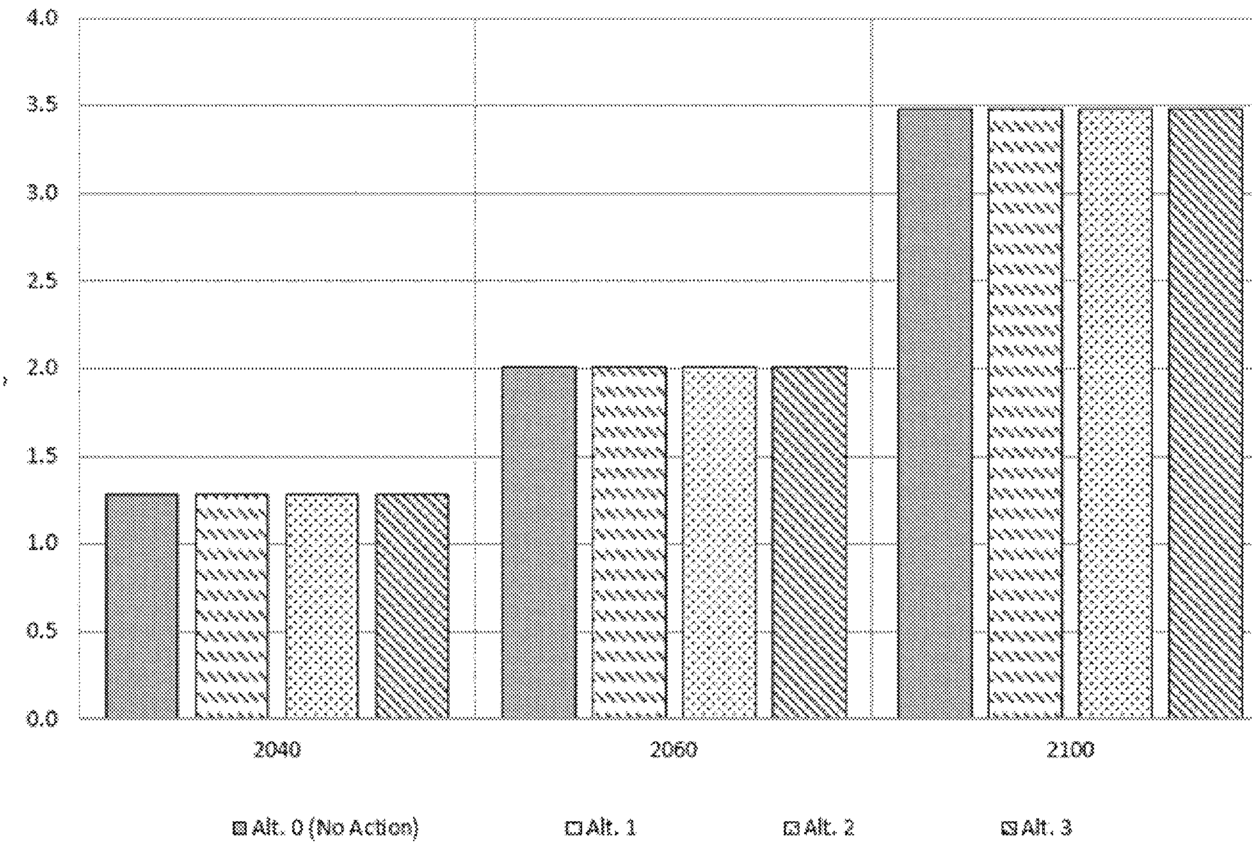


Figure 5.4.2-4 also illustrates that reduction in the growth of projected global mean surface temperature under the Proposed Action and alternatives compared to the No Action Alternative are anticipated to be small compared to total projected temperature increases. However, the relative impacts of the Proposed Action and alternatives can be seen by comparing the reductions in the rise in global mean surface temperature projected to occur under Alternatives 1 and 3. As shown in Figure 5.4.2-4, the reduction in the projected growth in global temperature under Alternative 3 is more than double that under Alternative 1 in 2100.

At this time, quantifying the changes in regional climate due to the Proposed Action and alternatives is not possible because of the limitations of existing climate models, but the Proposed Action and alternatives would be expected to reduce the regional impacts in proportion to reductions in global mean surface temperature increases. To provide context on how the projected changes in temperature from the MAGICC modeling may differentially affect geographic regions, Table 5.4.2-3 summarizes the regional changes in warming and seasonal temperatures presented in the IPCC AR5[TC "IPCC Fifth Assessment Report (AR5" \f A \l "1"] from present day through 2100.

Figure [STYLEREF 3 \s]-[SEQ Figure * ARABIC \s 3]. Reduction in Global Mean Surface Temperature Compared to the No Action Alternative

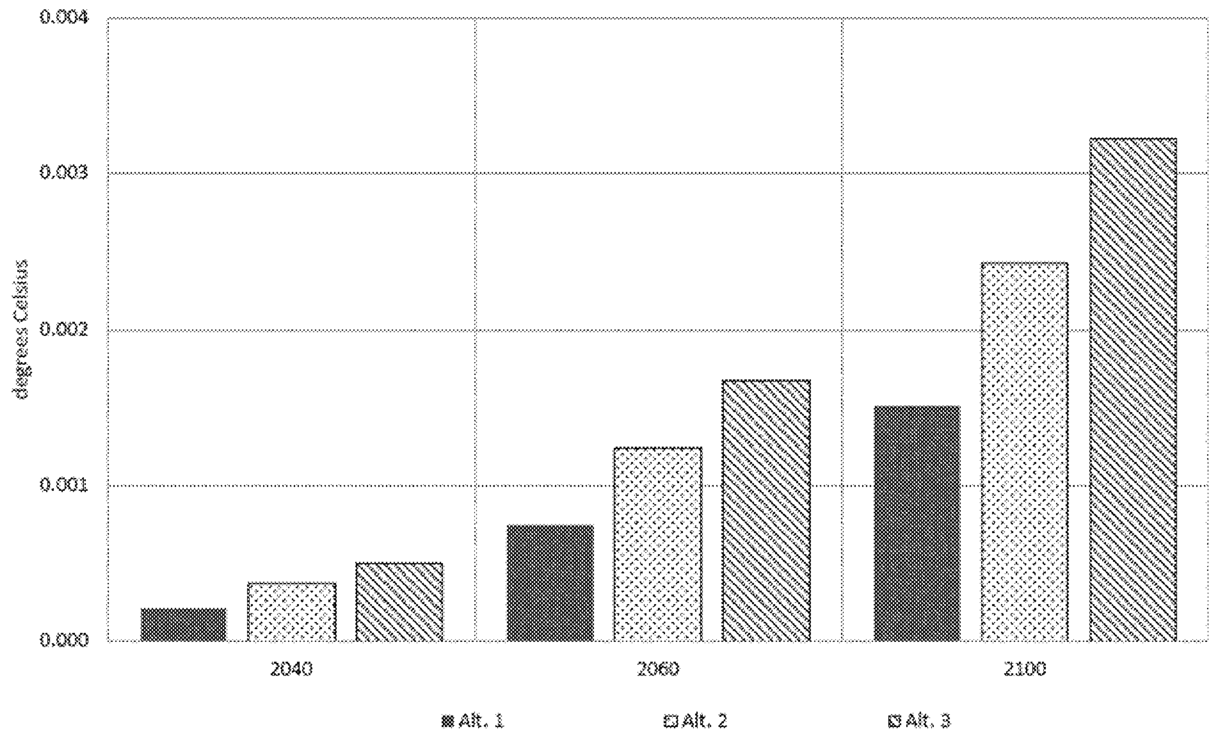


Table [STYLEREF 3 \s]-[SEQ Table * ARABIC \s 3]. Regional Changes to Warming and Seasonal Temperatures in the Year 2100 Compared to Current Conditions, Summarized from the IPCC Fifth Assessment Report

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
Africa	Northern Africa and Northern Sahara	*Very likely* increase in mean annual temperature[a,b] *Likely* increase throughout region to be higher than global mean annual warming[e]	*Likely* greater warming at night compared to day resulting in a reduction in future temperature rise[e]
	East Africa	*Very likely* increase in mean annual temperature[a,b]	--
	Southern Africa	*Very likely* increase in mean annual temperature[a,b] *Likely* higher mean land surface warming than global average	--
	Western Africa	*Very likely* increase in mean annual temperature[a,b]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, and increase in more frequent droughts

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
Mediterranean and Europe	Northern Europe	*Very likely* increase in mean annual temperature, *likely* greater increase in winter temperature than in Central or Southern Europe	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* more frequent heat waves (though little change over Scandinavia)
	Central Europe	*Very likely* increase in mean annual temperature, *likely* greater increase in summer temperature than in Northern Europe	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* more frequent heat waves
	Southern Europe and Mediterranean	*Very likely* increase in mean annual temperature, *likely* greater increase in summer temperature than in Northern Europe	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* more frequent heat waves
Asia	Central Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Northern Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Eastern Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	West Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	South Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Southeast Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
North America	Northern regions/ Northern North America	*Very likely* increase in mean annual temperature[a,b]	Minimum winter temperatures are *likely* to increase more than the average
	Southwest	*Very likely* increase in mean annual temperature[a,b]	--

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
Central and South America	Central America and the Caribbean	*Very likely* increase in temperatures	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Southeastern South America	*Very likely* increase in temperatures	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Amazon Region	*Very likely* increase in temperatures, greater than in other Central and South American locations	*Likely* increase in hot days and decrease in cool days, *very likely* increase in warm nights and decrease cold nights, *likely* increase in frequency and duration of heat waves
	Andes Region	*Very likely* increase in temperatures	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Northeastern Brazil	*Very likely* increase in temperatures	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
Australia and New Zealand	Southern Australia	*Virtually certain* increase in mean annual temperature	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves
	Southwestern Australia	*Virtually certain* increase in mean annual temperature	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves
	Rest of Australia	*Virtually certain* increase in mean annual temperature	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves
	New Zealand	*Virtually certain* increase in mean annual temperature	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
Polar Regions	Arctic	*Likely* that surface temperatures will be strongly influenced by anthropogenic forcing by mid-century	--
	Antarctic	*Very likely* to increase lower than global mean	--
Small Islands		*Very likely* increase in temperature	--

Notes:
Information is omitted from the table where no data was available from AR5.
Regional changes are provided for end-of-century compared to today's baseline, unless otherwise noted. Future modeled change can vary depending on a number of factors such as the concentration pathways used to drive the climate models (e.g., the amount of CO_2 emitted each year around the globe). The following superscripts were used to distinguish the various concentration pathways associated with specific findings:
[a] RCP2.6
[b] RCP8.5
[c] RCP4.5
[d] RCP6.0
[e] SRES A1B
No superscripts were used for those findings where the concentration pathways were not identified.
Source: IPCC 2013a

Sea-Level Rise

IPCC identifies five primary components of sea-level rise: thermal expansion of ocean water, melting of glaciers and ice caps, loss of land-based ice in Antarctica, loss of land-based ice in Greenland, and contributions from anthropogenic impacts on water storage (e.g., extraction of groundwater) (IPCC 2013a). Ocean circulation, changes in atmospheric pressure, and geological processes can also influence sea-level rise at a regional scale (EPA 2009). The Working Group I contribution to the IPCC AR5 (IPCC 2013a) projects the mean sea-level rise for each of the RCP scenarios. As noted in Section 5.3.3.2, *Sea-Level Rise,* NHTSA has used the relationship between the sea-level rise and temperature increases for each of the scenarios from IPCC AR5 to project sea-level rise in this SEIS.

IPCC AR5 projects ranges of sea-level rise for each of the RCP scenarios. For 2081 to 2100, sea-level rise is likely to increase 26 to 55 centimeters (10.2 to 21.7 inches) for RCP2.6, 32 to 63 centimeters (12.6 to 24.8 inches) for RCP4.5, 33 to 63 centimeters (13.0 to 24.8 inches) for RCP6.0, and 45 to 82 centimeters (17.7 to 32.3 inches) for RCP8.5 compared to 1986 to 2005 (IPCC 2013a). The 2019 IPCC Special Report on the Ocean and Cryosphere in a Changing Climate provides similar projections, with sea level likely to increase 29 to 59 centimeters (11.4 to 23.2 inches) for RCP2.6 and 61 to 110 centimeters (24.0 to 43.3 inches) for RCP8.5 compared to 1986 to 2005 (IPCC 2019a). Sea-level rise projections in the IPCC AR5 and 2019 Special Report are substantially higher than projections in the IPCC AR4 because they include significant contributions of melting from large ice sheets (in particular, Greenland and Antarctica) and mountain glaciers. Further, the contribution from anthropogenic impacts on land water, which were not included in AR4, also adds to the overall increase in projected sea-level rise (IPCC 2013a). However, IPCC results for sea-level projections are still lower than results modeled by some other studies, which were based largely on semi-empirical relationships (USACE 2014). NOAA notes that there is high confidence that the global mean sea level will rise at least 20 centimeters (8 inches) and no more than 200 centimeters (78 inches) by 2100 (GCRP 2014 citing Parris et al. 2012). See Section 5.3.3.2, *Sea-Level Rise*, for more information.

Table 5.4.2-2 lists the impacts of the Proposed Action and alternatives on sea-level rise under the GCAM Reference scenario. This analysis shows sea-level rise in 2100 ranging from 76.28 centimeters (30.03 inches) under the No Action Alternative to between 76.22 centimeters (30.01 inches) under Alternative 3 and 76.25 centimeters (30.02 inches) under Alternative 1. This represents a maximum reduction of 0.06 centimeter (0.03 inch) by 2100 under Alternative 3 compared to the No Action Alternative.

Precipitation

In some areas, the increase in energy available to the hydrologic cycle is expected to increase precipitation. Increases in precipitation result from higher temperatures causing more water evaporation, which causes more water vapor to be available for precipitation (EPA 2009). Increased evaporation leads to increased precipitation in areas where surface water is sufficient, such as over oceans and lakes. In drier areas, increased evaporation can actually accelerate surface drying (EPA 2009). Overall, according to the IPCC (IPCC 2013a), global mean precipitation is expected to increase under all climate scenarios. However, spatial and seasonal variations will be considerable. Generally, precipitation increases are very likely to occur in high latitudes, and decreases are likely to occur in the subtropics (EPA 2009).

MAGICC does not directly simulate changes in precipitation, and NHTSA has not undertaken precipitation modeling with a full AOGCM (further explained in Chapter 8, *Cumulative Impacts*). However, the IPCC (IPCC 2013a) summary of precipitation represents the most thoroughly reviewed, credible means of producing an assessment of this highly uncertain factor. NHTSA expects that the Proposed Action and alternatives would reduce anticipated changes in precipitation (i.e., in a reference case with no GHG emissions reduction policies) in proportion to the impacts of the alternatives on temperature.

The global mean change in precipitation provided by IPCC for the RCP8.5 (high), RCP6.0 (medium-high), RCP4.5 (medium) and RCP2.6 (low) scenarios (IPCC 2013a) is given as the scaled change in precipitation (expressed as a percentage change from 1980 to 1999 averages) divided by the increase in global mean surface warming for the same period (per °C), as shown in Table 5.4.2-4. IPCC provides average scaling factors in the year range of 2006 to 2100. NHTSA used the scaling factors for the RCP6.0 scenario (which has a radiative forcing in 2100 of 6 W/m^2, similar to the GCAM Reference scenario's radiative forcing of 7 W/m^2) in this analysis because MAGICC does not directly estimate changes in global mean precipitation.

Table [STYLEREF 3 \s]-[SEQ Table * ARABIC \s 3]. Rates of Global Mean Precipitation Increase over the 21st Century, per Emissions Scenario

Scenario	Percent per °C
RCP8.5	1.58
RCP6.0	1.68
RCP4.5	1.96
RCP2.6	2.39

Source: IPCC 2013a: Figure 12-7

Applying these scaling factors to the reductions in global mean surface warming provides estimates of changes in global mean precipitation. The Proposed Action and alternatives are projected to decrease temperature rise and predicted increases in precipitation slightly compared to the No Action Alternative, as shown in Table 5.4.2-5 (based on the scaling factor from the RCP6.0 scenario).

Table [STYLEREF 3 \s]-[SEQ Table * ARABIC \s 3]. Global Mean Precipitation (Percent Increase) Based on GCAM Reference Scenario Using Increases in Global Mean Surface Temperature Simulated by MAGICC, by Alternative[a]

Scenario	2040	2060	2100
Global Mean Precipitation Change (scaling factor, % change in precipitation per °C change in temperature)	1.68%		
Global Temperature Above Average 1986–2005 Levels (°C) for the GCAM Reference Scenario by Alternative			
Alt. 0 (No Action)	1.287	2.008	3.484
Alt. 1	1.287	2.007	3.483
Alt. 2	1.287	2.007	3.482
Alt. 3	1.287	2.007	3.481
Reductions in Global Temperature (°C) by Alternative, (Compared to the No Action Alternative)[b]			
Alt. 1	0.000	0.001	0.002
Alt. 2	0.000	0.001	0.002
Alt. 3	0.001	0.002	0.003
Global Mean Precipitation Increase by Alternative (%)			
Alt. 0 (No Action)	2.16%	3.37%	5.85%
Alt. 1	2.16%	3.37%	5.85%
Alt. 2	2.16%	3.37%	5.85%
Alt. 3	2.16%	3.37%	5.85%
Reductions in Global Mean Precipitation Increase by Alternative (% Compared to the No Action Alternative)			
Alt. 1	0.00%	0.00%	0.00%
Alt. 2	0.00%	0.00%	0.00%
Alt. 3	0.00%	0.00%	0.01%

Notes:
[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.
[b] Precipitation changes reported as 0.000 are more than zero but less than 0.001.
[c] The decrease in precipitation is less than 0.005%, and thus is rounded to 0.00%.
GCAM = Global Change Assessment Model; MAGICC = Model for the Assessment of Greenhouse-gas Induced Climate Change; °C = degrees Celsius

In addition to changes in mean annual precipitation, climate change is anticipated to affect the intensity of precipitation.[45] Regional variations and changes in the intensity of precipitation cannot be further quantified, primarily due to the lack of available AOGCMs required to estimate these changes. These

[45] As described in Meehl et al. 2007, the "intensity of precipitation events is projected to increase, particularly in tropical and high latitude areas that experience increases in mean precipitation. Even in areas where mean precipitation decreases (most subtropical and mid-latitude regions), precipitation intensity is projected to increase but periods between rainfall events would be longer. The mid-continental areas tend to dry during summer, indicating a greater risk of droughts in those regions. Precipitation extremes increase more than the mean in most tropical and mid- and high-latitude areas."

models typically are used to provide results among scenarios with very large changes in emissions, such as the RCP2.6 (low), RCP4.5 (medium), RCP6.0 (medium-high) and RCP8.5 (high) scenarios; very small changes in emissions profiles (such as those resulting from the Proposed Action and alternatives) would produce results that would be difficult to resolve among scenarios. In addition, the multiple AOGCMs produce results regionally consistent in some cases but inconsistent in others.

Quantifying the changes in regional climate under the Proposed Action and alternatives is not possible at this time, but the action alternatives would be expected to reduce the relative precipitation changes in proportion to the reduction in global mean surface temperature rise. To provide context on how the projected changes in precipitation from the MAGICC modeling may differentially affect geographic regions, Table 5.4.2-6 summarizes, in qualitative terms, the regional changes in precipitation from the IPCC AR5 from the present day through 2100.

Table [STYLEREF 3 \s]-[SEQ Table * ARABIC \s 3]. Regional Changes to Precipitation in the Year 2100 Compared to Current Conditions, Summarized from the IPCC Fifth Assessment Report

Land Area	Subregion	Precipitation	Snow Season and Snow Depth
Africa	Northern Africa and Northern Sahara	*Very Likely* decreases in mean annual precipitation[b]	--
	Eastern Africa	*Likely* increases in mean annual precipitation beginning mid-century[b] *Likely* to increase during short rainy season *Likely* increase in heavy precipitation	
	Central Africa	*Likely* increases in mean annual precipitation beginning mid-century[b]	
	Southern Africa	*Very likely* decreases in mean annual precipitation[b]	
	Western Africa	--	
Mediterranean and Europe	Northern Europe	--	*Likely* to decrease
	Central Europe	--	--
	Southern Europe and Mediterranean	*Likely* decrease in summer precipitation	--
Asia	Central Asia	*Very likely* increase in annual precipitation by mid-century[a]	--
	Northern Asia	*Very likely* increase in annual precipitation by mid-century[a]	
	Eastern Asia	Precipitation in boreal summer and winter is *likely* to increase. *Very likely* to be an increase in the frequency of intense precipitation. Extreme rainfall and winds associated with	

Land Area	Subregion	Precipitation	Snow Season and Snow Depth
		tropical cyclones are *likely* to increase	
	West Asia	--	--
	South Asia	*Very likely* increase in annual precipitation by end of century[a]	--
	Southeast Asia	*Very likely* increase in annual precipitation by end of century[a]	--
North America	Northern regions/Northern North America	*Very likely* increase in precipitation by mid-century[a]	Snow season length and snow depth are *very likely* to decrease
	Southwest	--	Snow season length and snow depth are *very likely* to decrease
	Northeast USA	--	Snow season length and snow depth are *very likely* to decrease
	Southern Canada	--	--
	Canada	*Very likely* increase in precipitation by mid-century[a]	Snow season length and snow depth are *very likely* to decrease
	Northernmost part of Canada	*Very likely* increase in precipitation by mid-century[a]	Snow season length and snow depth are *likely* to increase
Central and South America	Central America and the Caribbean	--	--
	Southeastern South America	*Very likely* that precipitation will increase	
	Amazon Region	*Very likely* that precipitation will decrease in the eastern Amazon during the dry season	
	Andes and Western South America	*Very likely* that precipitation will decrease in the Central Chile and the Northern part of this region	
	Northeastern Brazil	*Very likely* that precipitation will decrease during the dry season	
Australia and New Zealand	Southern Australia	--	--
	Southwestern Australia	--	
	New Zealand	*Likely* to increase in the western regions during winter and spring	
Polar Regions	Arctic	*Likely* increase in precipitation	--
	Antarctic	*Likely* increase in precipitation	
Small Islands	--	Rainfall *likely* to increase over certain regions	

Source: IPCC 2013a

Notes:
Information is omitted from the table where no data was available from IPCC AR5.
Regional changes are provided for end-of-century compared to today's baseline, unless otherwise noted. Future modeled change can vary depending on a number of factors such as the concentration pathways used to drive the climate models (e.g., the amount of CO_2 emitted each year around the globe). The following superscripts were used to distinguish the various concentration pathways associated with specific findings:
[a] RCP2.6
[b] RCP8.5

Ocean pH

Table 5.4.2-2 shows the projected increase of ocean pH under each action alternative compared to the No Action Alternative. Ocean pH under the alternatives ranges from 8.2176 under the No Action Alternative to 8.2180 under Alternative 3, for a maximum increase in pH of 0.0004 by 2100.

5.4.2.3 Climate Sensitivity Variations

Using the methods described in Section 5.3.3.6, *Sensitivity Analysis*, NHTSA examined the sensitivity of projected climate impacts on key technical or scientific assumptions used in the analysis. This examination included modeling the impact of various climate sensitivities on the climate effects under the No Action Alternative using the GCAM Reference scenario.

Table 5.4.2-7 lists the results from the sensitivity analysis, which included climate sensitivities of 1.5°C, 2.0°C, 2.5°C, 3.0°C, 4.5°C, and 6.0°C (2.7°F, 3.6°F, 4.5°F, 5.4°F, 8.1°F, and 10.8°F) for a doubling of CO_2 compared to preindustrial atmospheric concentrations (278 ppm CO_2) (Section 5.3.3.6, *Sensitivity Analysis*).

Table [STYLEREF 3 \s]-[SEQ Table * ARABIC \s 3]. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increases, Sea-Level Rise, and Ocean pH for Varying Climate Sensitivities for Selected Alternatives[a]

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea Level Rise (cm)[b]	Ocean pH
		2040	2060	2100	2040	2060	2100	2100	2100
Alt. 0 (No Action)	1.5	469.61	546.10	737.48	0.741	1.128	1.890	41.05	8.2445
	2.0	473.09	553.09	755.49	0.941	1.446	2.451	52.74	8.2350
	2.5	476.22	559.52	772.69	1.123	1.738	2.981	64.52	8.2260
	3.0	479.04	565.44	789.11	1.287	2.008	3.484	76.28	8.2176
	4.5	486.00	580.62	834.28	1.699	2.707	4.868	110.93	8.1952
	6.0	491.34	592.87	874.88	2.020	3.279	6.171	144.70	8.1759
Alt. 1	1.5	469.56	545.95	737.14	0.741	1.128	1.889	41.03	8.2447
	2.0	473.04	552.94	755.14	0.941	1.445	2.450	52.72	8.2351
	2.5	476.17	559.37	772.33	1.122	1.738	2.980	64.50	8.2262
	3.0	478.99	565.29	788.74	1.287	2.007	3.483	76.25	8.2178
	4.5	485.95	580.47	833.90	1.699	2.706	4.866	110.89	8.1954
	6.0	491.29	592.72	874.45	2.019	3.278	6.168	144.64	8.1761

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea Level Rise (cm)[b]	Ocean pH
		2040	2060	2100	2040	2060	2100	2100	2100
Alt. 2	1.5	469.53	545.85	736.95	0.740	1.127	1.889	41.02	8.2448
	2.0	473.01	552.85	754.94	0.941	1.445	2.449	52.71	8.2352
	2.5	476.14	559.27	772.12	1.122	1.737	2.979	64.48	8.2263
	3.0	478.96	565.19	788.52	1.287	2.007	3.482	76.23	8.2179
	4.5	485.92	580.37	833.65	1.698	2.705	4.865	110.86	8.1955
	6.0	491.26	592.61	874.21	2.019	3.277	6.167	144.59	8.1763
Alt. 3	1.5	469.50	545.77	736.77	0.740	1.127	1.888	41.01	8.2449
	2.0	472.98	552.76	754.76	0.941	1.445	2.449	52.70	8.2353
	2.5	476.11	559.19	771.94	1.122	1.737	2.978	64.47	8.2264
	3.0	478.93	565.11	788.33	1.287	2.007	3.481	76.22	8.2180
	4.5	485.89	580.28	833.45	1.698	2.705	4.864	110.83	8.1956
	6.0	491.23	592.53	873.98	2.019	3.277	6.165	144.56	8.1764
Reductions Under Alternative 1 Compared to No Action Alternative									
Alt. 1	1.5	0.05	0.15	0.34	0.000	0.000	0.001	0.01	-0.0002
	2.0	0.05	0.15	0.35	0.000	0.001	0.001	0.02	-0.0002
	2.5	0.05	0.15	0.36	0.000	0.001	0.001	0.02	-0.0002
	3.0	0.05	0.15	0.37	0.000	0.001	0.002	0.03	-0.0002
	4.5	0.05	0.16	0.37	0.000	0.001	0.002	0.05	-0.0002
	6.0	0.05	0.16	0.43	0.000	0.001	0.003	0.06	-0.0002
Reductions Under Alternative 2 Compared to No Action Alternative									
Alt. 2	1.5	0.08	0.24	0.54	0.000	0.001	0.001	0.02	-0.0003
	2.0	0.08	0.25	0.55	0.000	0.001	0.002	0.03	-0.0003
	2.5	0.08	0.25	0.57	0.000	0.001	0.002	0.04	-0.0003
	3.0	0.08	0.25	0.58	0.000	0.001	0.002	0.05	-0.0003
	4.5	0.08	0.25	0.62	0.000	0.002	0.003	0.08	-0.0003
	6.0	0.08	0.26	0.67	0.000	0.002	0.005	0.11	-0.0003
Reductions Under Alternative 3 Compared to No Action Alternative									
Alt. 3	1.5	0.11	0.32	0.71	0.000	0.001	0.002	0.03	-0.0004
	2.0	0.11	0.33	0.73	0.000	0.001	0.002	0.04	-0.0004
	2.5	0.11	0.33	0.75	0.000	0.001	0.003	0.05	-0.0004
	3.0	0.11	0.33	0.77	0.001	0.002	0.003	0.06	-0.0004
	4.5	0.11	0.34	0.83	0.001	0.002	0.004	0.10	-0.0004
	6.0	0.11	0.35	0.91	0.001	0.002	0.006	0.14	-0.0004

Notes:
[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact difference of the values.
[b] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986–2005.
ppm = parts per million; °C = degrees Celsius; CO_2 = carbon dioxide; cm = centimeters

As the tables show, varying climate sensitivities (the equilibrium warming that occurs at a doubling of CO_2 from preindustrial levels) can affect not only estimated warming, but also estimated sea-level rise, ocean pH, and atmospheric CO_2 concentration. This complex set of interactions occurs because both atmospheric CO_2 and temperature affect ocean absorption of atmospheric CO_2, which reduces ocean pH. Specifically, higher temperatures result in lower aqueous solubility of CO_2, while higher concentrations of atmospheric CO_2 lead to more ocean absorption of CO_2. Atmospheric CO_2 concentrations are affected by the amount of ocean carbon storage. Therefore, as Table 5.4.2-7 shows, projected future atmospheric CO_2 concentrations differ with varying climate sensitivities even under the same alternative, despite the fact that CO_2 emissions are fixed under each alternative.

Simulated atmospheric CO_2 concentrations in 2040, 2060, and 2100 are a function of changes in climate sensitivity. The small changes in concentration are due primarily to small changes in the aqueous solubility of CO_2 in ocean water: slightly warmer air and sea surface temperatures lead to less CO_2 being dissolved in the ocean and slightly higher atmospheric concentrations.

The response of simulated global mean surface temperatures to variation in the climate sensitivity parameter varies among the years 2040, 2060, and 2100, as shown in Table 5.4.2-7. In 2040, the impact of assumed variation in climate sensitivity is low, due primarily to the limited rate at which the global mean surface temperature increases in response to increases in radiative forcing. In 2100, the impact of variation in climate sensitivity is magnified by the larger change in emissions. The increase in 2100 global mean surface temperature from the No Action Alternative to Alternative 3 ranges from 0.002°C (0.004°F) for the 1.5°C (2.7°F) climate sensitivity to 0.006°C (0.011°F) for the 6.0°C (10.8°F) climate sensitivity.

The sensitivity of the simulated sea-level rise to change in climate sensitivity and global GHG emissions mirrors that of global temperature, as shown in Table 5.4.2-7. Scenarios with lower climate sensitivities show generally smaller increases in sea-level rise; at the same time, sea-level rise is lower under the Proposed Action and alternatives compared to the No Action Alternative. Conversely, scenarios with higher climate sensitivities have higher projected sea-level rise; again, however, sea-level rise is lower under the Proposed Action and alternatives compared to the No Action Alternative. The range in reductions of sea-level rise under Alternative 3 compared to the No Action Alternative is 0.03 to 0.14 centimeter (0.012 to 0.055 inch), depending on the assumed climate sensitivity.